



ANNUAL REPORT OF THE
BOARD OF REGENTS OF
THE SMITHSONIAN
INSTITUTION

SHOWING THE
OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDED JUNE 30

1950



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LETTER OF TRANSMITTAL

SMITHSONIAN INSTITUTION,
Washington, December 28, 1950.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, on behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1950. I have the honor to be,

Respectfully,

A. WETMORE, *Secretary.*

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THE SMITHSONIAN INSTITUTION

June 30, 1950

Presiding Officer ex officio.—HARRY S. TRUMAN, President of the United States.

Chancellor.—FRED M. VINSON, Chief Justice of the United States.

Members of the Institution:

HARRY S. TRUMAN, President of the United States.

ALBEN W. BARKLEY, Vice President of the United States.

FRED M. VINSON, Chief Justice of the United States.

DEAN C. ACHESON, Secretary of State.

JOHN W. SNYDER, Secretary of the Treasury.

LOUIS JOHNSON, Secretary of Defense.

J. HOWARD McGRATH, Attorney General.

JESSE M. DONALDSON, Postmaster General.

OSCAR CHAPMAN, Secretary of the Interior.

CHARLES F. BRANNON, Secretary of Agriculture.

CHARLES SAWYER, Secretary of Commerce.

MAURICE TOBIN, Secretary of Labor.

Regents of the Institution:

FRED M. VINSON, Chief Justice of the United States, Chancellor.

ALBEN W. BARKLEY, Vice President of the United States.

WALTER F. GEORGE, Member of the Senate.

CLINTON P. ANDERSON, Member of the Senate.

LEVERETT SALTONSTALL, Member of the Senate.

CLARENCE CANNON, Member of the House of Representatives.

JOHN M. VORYS, Member of the House of Representatives.

E. E. COX, Member of the House of Representatives.

HARVEY N. DAVIS, citizen of New Jersey.

ARTHUR H. COMPTON, citizen of Missouri.

VANNEVAR BUSH, citizen of Washington, D. C.

ROBERT V. FLEMING, citizen of Washington, D. C.

JEROME C. HUNSAKER, citizen of Massachusetts.

Executive Committee.—ROBERT V. FLEMING, chairman, VANNEVAR BUSH, CLARENCE CANNON.

Secretary.—ALEXANDER WETMORE.

Assistant Secretary.—JOHN E. GRAF.

Assistant Secretary.—J. L. KEDDY.

Administrative assistant to the Secretary.—MRS. LOUISE M. PEARSON.

Treasurer.—J. D. HOWARD.

Chief, editorial division.—PAUL H. OEHSER.

Librarian.—MRS. LEILA F. CLARK.

Administrative accountant.—THOMAS F. CLARK.

Superintendent of buildings and labor.—L. L. OLIVER.

Assistant Superintendent of buildings and labor.—CHARLES C. SINCLAIR.

Personnel officer.—MRS. B. T. CARWITHEN.

Chief, division of publications.—L. E. COMMERFORD.

Property, supply, and purchasing officer.—ANTHONY W. WILDING.

Photographer.—F. B. KESTNER.

UNITED STATES NATIONAL MUSEUM

Director.—A. REMINGTON KELLOGG.

Chief, office of correspondence and records.—HELENA M. WEISS.

Editor.—PAUL H. OEHSER, *acting*.

Associate librarian.—MRS. ELISABETH H. GAZIN.

SCIENTIFIC STAFF

DEPARTMENT OF ANTHROPOLOGY:

Frank M. Setzler, head curator; A. J. Andrews, chief preparator; W. W. Taylor, Jr., collaborator in anthropology.

Division of Archeology: Waldo R. Wedel, curator; Mrs. M. C. Blaker, museum aide; J. Townsend Russell, Jr., honorary assistant curator of Old World archeology.

Division of Ethnology: H. W. Krieger, curator; J. C. Ewers, associate curator; C. M. Watkins, associate curator; R. A. Elder, Jr., assistant curator.

Division of Physical Anthropology: T. Dale Stewart, curator; M. T. Newman, associate curator.

Associate in Anthropology: Neil M. Judd.

DEPARTMENT OF ZOOLOGY:

Waldo L. Schmitt, head curator; W. L. Brown, chief taxidermist; Mrs. Aime M. Awl, scientific illustrator.

Associates in Zoology: T. S. Palmer, W. B. Marshall, A. G. Böving, C. R. Shoemaker, W. K. Fisher.

Collaborator in Zoology: R. S. Clark.

Collaborator in Biology: D. C. Graham.

Division of Mammals: D. H. Johnson, associate curator; H. W. Setzer, associate curator; N. M. Miller, museum aide; A. Brazier Howell, collaborator; Gerrit S. Miller, Jr., associate.

Division of Birds: Herbert Friedmann, curator; H. G. Deignan, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Arthur C. Bent, collaborator.

Division of Reptiles and Amphibians: Doris M. Cochran, associate curator.

Division of Fishes: Leonard P. Schultz, curator; E. A. Lachner, associate curator; W. T. Leapley, museum aide.

Division of Insects: Edward A. Chapin, curator; R. E. Blackwelder, associate curator; W. D. Field, associate curator; O. L. Cartwright, associate curator; Grace E. Glance, associate curator; W. L. Jellison, collaborator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Division of Marine Invertebrates: F. A. Chace, Jr., curator; P. L. Illg, associate curator; Frederick M. Bayer, assistant curator; Mrs. L. W. Peterson, J. T. Willett, museum aides; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; J. Percy Moore, collaborator; Mrs. M. S. Wilson, collaborator in copepod Crustacea.

Division of Mollusks: Harald A. Rehder, curator; Joseph P. E. Morrison, associate curator; R. Tucker Abbott, associate curator; W. J. Byas, museum aide; Paul Bartsch, associate.

Section of Helminthological Collections: Benjamin Schwartz, collaborator.

Division of Echinoderms: Austin H. Clark, curator.

DEPARTMENT OF BOTANY (NATIONAL HERBARIUM):

E. P. Killip, head curator.

Division of Phanerogams: A. C. Smith, curator; E. C. Leonard, associate curator; E. H. Walker, associate curator; Lyman B. Smith, associate curator; Velva E. Rudd, assistant curator.

Division of Ferns: C. V. Morton, curator.

Division of Grasses: Jason R. Swallen, curator; Mrs. Agnes Chase, research associate; F. A. McClure, research associate.

Division of Cryptogams: E. P. Killip, acting curator; Paul S. Conger, associate curator; G. A. Llano, associate curator; John A. Stevenson, custodian of C. G. Lloyd mycological collections; W. T. Swingle, custodian of Higher Algae; David Fairchild, custodian of Lower Fungi.

DEPARTMENT OF GEOLOGY:

W. F. Foshag, head curator; J. H. Benn, museum aide; Jessie G. Beach, aid.

Division of Mineralogy and Petrology: W. F. Foshag, acting curator; E. P. Henderson, associate curator; G. S. Switzer, associate curator; F. E. Holden, museum technician; Frank L. Hess, custodian of rare metals and rare earths.

Division of Invertebrate Paleontology and Paleobotany: Gustav A. Cooper, curator; A. R. Loeblich, Jr., associate curator; David Nicol, associate curator; W. T. Allen, museum aide; J. Brookes Knight, research associate in paleontology.

Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; J. B. Reeside, Jr., custodian of Mesozoic collection.

Division of Vertebrate Paleontology: C. L. Gazin, curator; D. H. Dunkle, associate curator; F. L. Pearce, exhibits preparator; W. D. Crockett, scientific illustrator; A. C. Murray, exhibits preparator.

Associates in Mineralogy: W. T. Schaller, S. H. Perry, J. P. Marble.

Associates in Paleontology: T. W. Vaughan, R. S. Bassler.

DEPARTMENT OF ENGINEERING AND INDUSTRIES:

Frank A. Taylor, head curator.

Division of Engineering: Frank A. Taylor, acting curator.

Section of Civil and Mechanical Engineering: Frank A. Taylor, in charge.

Section of Marine Transportation: Frank A. Taylor, in charge.

Section of Electricity: K. M. Perry, associate curator.

Section of Physical Sciences and Measurement: Frank A. Taylor, in charge.

Section of Land Transportation: S. H. Oliver, associate curator.

Division of Crafts and Industries: W. N. Watkins, curator; F. C. Reed, associate curator; E. A. Avery, museum aide; F. L. Lewton, research associate.

Section of Textiles: Grace L. Rogers, assistant curator.

Section of Wood Technology: William N. Watkins, in charge.

Section of Manufactures: F. C. Reed, in charge.

Section of Agricultural Industries: F. C. Reed, in charge.

Division of Medicine and Public Health: G. S. Thomas, associate curator.

Division of Graphic Arts: Jacob Kainen, curator; E. J. Fite, museum aide.

Section of Photography: A. J. Wedderburn, Jr., associate curator.

DEPARTMENT OF HISTORY:

Charles Carey, acting head curator.
Divisions of Military History and Naval History: M. L. Peterson, associate curator; J. R. Sirlouis, assistant curator.
Division of Civil History: Margaret W. Brown, assistant curator.
Division of Numismatics: S. M. Mosher, associate curator.
Division of Philately: Mrs. C. L. Manning, assistant curator.

NATIONAL GALLERY OF ART

Trustees:

FRED M. VINSON, Chief Justice of the United States, *Chairman*.
 DEAN C. ACHESON, Secretary of State.
 JOHN W. SNYDER, Secretary of the Treasury.
 ALEXANDER WETMORE, Secretary of the Smithsonian Institution.
 SAMUEL H. KRESS.
 FERDINAND LAMMOT BELIN.
 DUNCAN PHILLIPS.
 CHESTER DALE.
 PAUL MELLON.

President.—SAMUEL H. KRESS.
Vice President.—FERDINAND LAMMOT BELIN.
Secretary-Treasurer.—HUNTINGTON CAIRNS.
Director.—DAVID E. FINLEY.
Administrator.—HARRY A. MCBRIDE.
General Counsel.—HUNTINGTON CAIRNS.
Chief Curator.—JOHN WALKER.
Assistant Director.—MACGILL JAMES.

NATIONAL COLLECTION OF FINE ARTS

Director.—THOMAS M. BEGGS.
Curator of ceramics.—P. V. GARDNER.
Exhibits preparator.—G. J. MARTIN.
Assistant librarian.—ANNA M. LINK.

FREER GALLERY OF ART

Director.—A. G. WENLEY.
Assistant Director.—JOHN A. POPE.
Associate in Near Eastern art.—RICHARD ETTINGHAUSEN.
Research associate.—GRACE DUNHAM GUEST.

BUREAU OF AMERICAN ETHNOLOGY

Director.—MATTHEW W. STIRLING.
Associate Director.—FRANK H. H. ROBERTS, JR.
Senior ethnologists.—H. B. COLLINS, JR., JOHN P. HARRINGTON, W. N. FENTON.
Senior anthropologist.—G. R. WILLEY.
Collaborators.—FRANCES DENSMORE, JOHN R. SWANTON, A. J. WARING, JR.
Editor.—M. HELEN PALMER.
Assistant librarian.—MIRIAM B. KETCHUM.
Scientific illustrator.—E. G. SCHUMACHER.
Archives assistant.—MAE W. TUCKER.

INSTITUTE OF SOCIAL ANTHROPOLOGY.—G. M. FOSTER, Jr., *Director*¹; GORDON R. WILLEY, *Acting Director*.
RIVER BASIN SURVEYS.—FRANK H. H. ROBERTS, Jr., *Director*.

INTERNATIONAL EXCHANGE SERVICE

Chief.—D. G. WILLIAMS.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.
Assistant Director.—ERNEST P. WALKER.
Head Keeper.—FRANK O. LOWE.

ASTROPHYSICAL OBSERVATORY

Director.—LOYAL B. ALDRICH.
Assistant librarian.—MARJORIE R. KUNZE.
DIVISION OF ASTROPHYSICAL RESEARCH:
Chief.—WILLIAM H. HOOVER.
Instrument makers.—ANDREW KRAMER, D. G. TALBERT, J. H. HARRISON.
Research associate.—CHARLES G. ABBOT.
DIVISION OF RADIATION AND ORGANISMS:
Chief.—R. B. WITHROW.
Plant physiologist.—LEONARD PRICE.
Biological aide (botany).—V. B. ELSTAD.

NATIONAL AIR MUSEUM

Advisory Board:
ALEXANDER WETMORE, *Chairman*.
LT. GEN. K. B. WOLFE, *U. S. Air Force*.
REAR ADM. A. M. PRIDE, *U. S. Navy*.
GROVER LOENING.
WILLIAM B. STOUT.
Assistant to the Secretary for the National Air Museum.—CARL W. MITMAN.
Curator.—P. E. GARBER.
Associate curators.—S. L. BEERS, R. C. STROBELL, W. M. MALE.
Exhibits preparator.—S. L. POTTER.

CANAL ZONE BIOLOGICAL AREA

Resident Manager.—JAMES ZETEK.

¹ In absentia as of June 30, 1950.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

ALEXANDER WETMORE

FOR THE YEAR ENDED JUNE 30, 1950

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and its branches during the fiscal year ended June 30, 1950.

GENERAL STATEMENT

The activities of the Smithsonian Institution, now as when it was established more than a century ago, are geared to the broad purposes stated by the founder, James Smithson. He wanted, he said in his famous will, "to found at Washington an institution for the increase and diffusion of knowledge among men." These words have had a far-reaching effect on American science, for they not only enabled the Institution to operate without excessive restrictions and with freedom of initiative and outlook, but also they became the pattern for other foundations established during the course of the nineteenth century.

In this day of increasing pressures on all sides and definite trends in certain countries toward the regimentation of science, the necessity for this freedom of inquiry under which the Smithsonian has existed cannot be too strongly emphasized.

The Institution has never sought to expand its programs inordinately, or to add functions unjustified by normal demands or necessities. It has been conservative, yet pioneering, and it would not be difficult to cite instances where small and perhaps unpopular projects, modestly aided by Smithsonian encouragement or financial grants, developed into enterprises of considerable scope and importance. When the Institution began its operations in 1846, it carried on its research programs largely by subsidizing the work of scientists not on its own staff and by publishing the results of their work. As these pioneer researches expanded and became somewhat stabilized, bureaus gradually grew up around the Institution, each with its own staff specializing in the work of that particular field. The value of the various activities gradually became known to the Nation, and eventually one by one they were recognized as public necessities by

the Congress. Most of them are now supported largely by Government funds although remaining under Smithsonian direction. At present, nearly all the research and exploration of the Institution is done through these bureaus, notably the United States National Museum, the Bureau of American Ethnology, and the Astrophysical Observatory.

Unfortunately, the governmental support of the branches of the Institution, now ten in number, has not kept pace with even the normal exigencies of modern times. The greatest deficiency at the present time is in the physical plant and facilities. As I have pointed out in previous reports, the problem of housing the constantly increasing collections of the National Museum is so critical that important material must be refused because there is no space to store it, to say nothing of exhibiting it. The Natural History Building at Constitution Avenue and Tenth Street and the 80-year-old Arts and Industries Building to the south are so crowded that the task of accommodating new accessions becomes a juggling game. Alleviation of these conditions awaits the time when Congress appropriates funds for the new buildings we have under consideration.

Throughout the period of the two world wars and the intervening "depression," many of our museum exhibits, though adequate enough in their day, became badly out of date and in need of drastic renovation. During the past 2 or 3 years it has been possible to begin the job of modernizing these exhibits, and the work will go forward as rapidly as funds for the purpose become available. This is a large and time-consuming undertaking, but one that is vital to the Institution's educational program. During the past year more than 2,600,000 persons visited the Smithsonian group of buildings. It is our obligation, so far as our funds and facilities permit, to extend to this large cross section of the public (many of whom are students) all possible courtesies and assistance and to make their visits stimulating and rewarding.

For the most part the year saw few major changes in the Institution's staff. In many departments shortages of personnel continue to exist, a situation that can be remedied only as rapidly as new positions are provided for by budgetary and congressional authorization. On May 31, 1950, Webster Prentiss True retired as chief of the editorial division after nearly 36 years with the Institution and was succeeded in that position on June 1 by Paul H. Oehser, assistant chief of the division and editor of the National Museum. Dr. Leland O. Howard, veteran entomologist and honorary curator of insects of the National Museum, died on May 1, 1950; Dr. Henri Pittier, associate in botany, on January 27, 1950.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

No changes occurred in the personnel of the Board of Regents during the year. There still exists one vacancy in the class of citizen regents.

The roll of regents at the close of the fiscal year, June 30, 1950, was as follows: Chief Justice Fred M. Vinson, Chancellor; Vice President Alben W. Barkley; members from the Senate: Walter F. George, Clinton P. Anderson, Leverett Saltonstall; members from the House of Representatives: Clarence Cannon, John M. Vorys, E. E. Cox; citizen members: Harvey N. Davis, Arthur H. Compton, Vannevar Bush, Robert V. Fleming, and Jerome C. Hunsaker.

Proceedings.—The annual meeting of the Board of Regents was held on January 13, 1950. Present: Chief Justice Fred M. Vinson, Chancellor; Representative Clarence Cannon, Representative John M. Vorys; Senator Clinton P. Anderson; Dr. Robert V. Fleming, Dr. Vannevar Bush, Dr. Jerome C. Hunsaker, Secretary Alexander Wetmore, and Assistant Secretary John E. Graf.

The Secretary presented his annual report covering the activities of the Institution and its bureaus, including the financial report of the Executive Committee, for the fiscal year ended June 30, 1949, which was accepted by the Board. The usual resolution authorized the expenditure by the Secretary of the income of the Institution for the fiscal year ending June 30, 1951.

The Secretary reported that in connection with surveys for construction of Government dams throughout the country there has been much interest in the salvage of scientific materials that would be covered by impounded waters. In connection with this, Congressman Curtis of Nebraska introduced in the House a bill, H. R. 2290, to provide for cooperation by the Smithsonian Institution with State, educational, and scientific organizations for fossil studies in areas to be flooded by the construction of Government dams. This bill,

including an authorization for an appropriation of \$65,000, passed the House and the Senate and was approved by the President on August 15, 1949.

The Board was advised that Congress had recently requested the Bureau of the Budget to contact all Federal agencies that were carrying on activities with the aid of Federal appropriations without having clear-cut basic authority therefor to advise them to submit drafts of bills proposing the requisite authorizations. In accordance with this, a draft of legislation was prepared to cover the activities of the Bureau of American Ethnology, the Astrophysical Observatory, and certain miscellaneous housekeeping functions that had been carried on for many years but had not been clearly authorized by basic legislation. The Bureau of American Ethnology was established in 1879 "for the purpose of continuing ethnological researches among the North American Indians under the direction of the Smithsonian Institution," with annual appropriation for this purpose, but without formal authorization other than that of the appropriation acts. The Astrophysical Observatory was founded, in similar manner, in 1890, for the measurement and analysis of solar radiation, and since 1891 has received annual appropriations. Further, Congress has appropriated funds since 1886 for the maintenance of Smithsonian buildings and grounds, and since 1896 for the preparation of manuscripts, drawings, and illustrations for publication. The Honorable Clarence Cannon, regent, introduced H. R. 3417 on March 10, 1949, containing the authorizations needed. This duly passed the House of Representatives, and in the Senate the matter received the attention of Senator Clinton P. Anderson, regent, and the friendly consideration of Senator Carl Hayden, chairman of the Committee on Rules and Administration, to the end that the act passed the Senate and on August 22, 1949, was signed by the President. This places these activities, some of which have been in operation for over 70 years, on firm legal basis.

Developments concerning the Gellatly art collection since the previous meeting of the Board were reported as follows by the Secretary: At the annual meeting last year, it was reported that the action of Mrs. Charlayne Whiteley Gellatly against the Secretary, in an attempt to recover the Gellatly collection from the Secretary in his status as a private individual though acting as custodian under the Smithsonian Institution, had been carried to the United States Court of Appeals for the District of Columbia Circuit, following decision in favor of the Secretary in the District Court of the United States for the District of Columbia. Under date of September 28, 1949, the United States Court of Appeals issued an order stating that the court, having duly considered a petition for a rehearing, had denied the

rehearing. The Institution was represented in this action by the Department of Justice through Marvin C. Taylor, special attorney.

On the evening of January 12, 1950, an informal dinner meeting of the Board was held in the Main Hall of the Smithsonian Institution, with the Chancellor, Chief Justice Fred M. Vinson, presiding. This occasion gave opportunity for members of the Smithsonian staff to make a fuller presentation of the scientific work of the Institution than was practicable at the regular meeting the next day.

FINANCES

A statement on finances, dealing particularly with Smithsonian private funds, will be found in the report of the Executive Committee of the Board of Regents, page 156.

APPROPRIATIONS

Funds appropriated to the Institution for the fiscal year ended June 30, 1950, totaled \$2,346,000, allotted as follows:

Management.....	\$52, 574
United States National Museum.....	715, 484
Bureau of American Ethnology.....	61, 897
Astrophysical Observatory.....	109, 666
National Collection of Fine Arts.....	38, 857
National Air Museum.....	200, 864
Canal Zone Biological Area.....	5, 000
International Exchange Service.....	69, 180
Maintenance and operation of buildings.....	786, 714
General services.....	304, 655
Estimated savings.....	1, 109
Total.....	2, 346, 000

In addition \$1,114,700 was appropriated to the National Gallery of Art, a bureau of the Institution but administered by a separate board of trustees; and \$544,700 was provided in the District of Columbia appropriation act for the operation of the National Zoological Park.

Besides these direct appropriations, the Institution received funds by transfer from other Federal agencies, as follows:

From the State Department, from the appropriation Cooperation with the American Republics, 1950, a total of \$82,510 for the operation of the Institute of Social Anthropology, including the issuance of publications resulting from its work.

From the National Park Service, Department of the Interior, \$215,886 for archeological projects in connection with River Basin Surveys.

VISITORS

Visitors to the Smithsonian buildings during the year totaled 2,600,758, only slightly less than last year's all-time record of attendance. March 1950 was the month of largest attendance, with 371,811 visitors; August 1949 was the next largest, with 349,318. A summary of attendance records for the five buildings is given in table 1:

TABLE 1.—Visitors to the Smithsonian buildings during the year ended June 30, 1950

Year and month	Smithsonian Building	Arts and Industries Building	Natural History Building	Aircraft Building	Freer Gallery of Art	Total
<i>1949</i>						
July.....	65,007	149,084	75,627	22,763	7,954	320,435
August.....	72,446	158,653	86,490	23,179	8,550	349,318
September.....	43,497	97,510	56,072	13,540	7,932	218,551
October.....	31,946	73,702	55,248	11,979	4,835	177,710
November.....	24,818	51,729	38,732	9,933	3,261	128,473
December.....	16,512	32,125	27,628	6,559	1,951	84,775
<i>1950</i>						
January.....	19,929	40,461	35,166	8,125	2,772	106,453
February.....	19,800	39,770	34,968	8,214	2,687	105,439
March.....	22,660	48,608	41,311	8,698	2,976	124,253
April.....	66,915	172,514	105,430	19,308	7,644	371,811
May.....	54,600	143,966	91,717	17,603	5,653	313,599
June.....	57,729	141,897	76,559	17,170	6,586	299,941
Total.....	495,919	1,150,019	724,948	167,071	62,801	2,600,758

SEVENTEENTH ANNUAL JAMES ARTHUR LECTURE ON THE SUN

In 1931 the Institution received a bequest from James Arthur, of New York, a part of the income from which was to be used for an annual lecture on some aspect of the study of the sun.

The seventeenth Arthur lecture was delivered in the auditorium of the Natural History Building on April 6, 1950, by Dr. Bertil Lindblad, Director of the Stockholm Observatory, Stockholm, Sweden. The subject of Dr. Lindblad's address was "The Luminous Surface and Atmosphere of the Sun." His lecture is published in full in the General Appendix of the present Report of the Board of Regents (p. 173.)

SUMMARY OF THE YEAR'S ACTIVITIES OF THE BRANCHES OF THE INSTITUTION

National Museum.—The national collections were increased during the year by approximately 793,300 specimens, a large increase over the previous year, bringing the total number of catalog entries in all six departments to 32,375,597. Noteworthy accessions for the year included: In anthropology, nearly a thousand pottery, stone, and other objects from the Neolithic period of northern Honshu, Japan, and a further lot of ethnological specimens obtained in northern Australia by the 1948 expedition to Arnhem Land sponsored by the

Commonwealth of Australia, the National Geographic Society, and the Smithsonian Institution; in zoology, about 10,000 skins and over 400 skeletons of North American birds from one donor, 4,500 fishes from the Gulf of Mexico, a collection of 15,000 British Microlepidoptera, a bequest of 10,500 beetles, and sizable lots of marine invertebrates from Arctic America; in botany, large collections of plants from Perú, New Zealand, Colombia, and Africa; in geology, 24 kinds of minerals hitherto unrepresented in the national collections, several new meteorites, many thousand invertebrate fossils (including the large and important Cushman and Vaughan collections of Foraminifera and the Renfro fossil-invertebrate collection of 250,000 specimens), and skeletal remains of the giant ground sloth *Megatherium* from western Panamá; in engineering and industries, exhibition material illustrating the operation of a textile-finishing mill and 51 examples of the work of the pioneering photographer Victor Prevost; and in history, a silver-filigree basket reputed to have belonged to Napoleon, two outstanding models of historic ships, and several interesting philatelic and numismatic acquisitions.

Field work by members of the Museum staff or by collaborators was conducted in Colombia, Guatemala, Panamá, Alaska and the Arctic, Africa, the West Indies, and many sections of the United States. The Museum issued 29 publications.

National Gallery of Art.—Visitors to the Gallery during the year reached a total of 2,187,293, a daily average attendance of 6,025 persons. This represented a daily increase of 1,800 over the previous year's record. Accessions as gifts, loans, or deposits numbered 2,354. Ten special exhibitions were held at the Gallery, including a 2-month showing of the celebrated "Art Treasures from the Vienna Collections," lent by the Austrian Government, and "Makers of History in Washington, 1800-1950," an exhibit that opened on June 29, 1950, celebrating the sesquicentennial of the establishment of the Federal Government in Washington. Special exhibitions of prints from the Rosenwald collection were circulated to seven galleries and museums in this country and Canada, and exhibitions from the "Index of American Design" were shown at 34 institutions in 17 States, the District of Columbia, and London, England. Over 20,000 photographs were acquired from European museums and are being cataloged and filed. The staff continued to answer hundreds of inquiries and to give opinion on works of art brought to the Gallery and advice on research problems in art. The volume "Masterpieces of Sculpture from the National Gallery of Art," by Charles Seymour, Jr., was placed on sale during the year, and a second volume of "Masterpieces of Painting," by Huntington Cairns and John Walker, was in process. More than 28,000 persons attended the special tours of the Gallery,

26,000 the "Picture of the Week" talks, and 17,000 the 13 Sunday-afternoon lectures in the auditorium. Forty-five Sunday-evening concerts were given in the East Garden Court. The work of construction of new galleries and offices for expanding activities continued, and 12 new galleries were opened, 8 just prior to and 4 just after the end of the fiscal year.

National Collection of Fine Arts.—The Smithsonian Art Commission met on December 6, 1949, and accepted two paintings for the National Collection. One miniature was acquired through the Catherine Walden Myer fund. Thirteen special art exhibitions were held during the year, especially noteworthy being a 4½-month showing of paintings by Abbott Handerson Thayer (1849–1921) in commemoration of the centennial of this artist's birth and featuring his studies on camouflage and on protective coloration in the Animal Kingdom; and an exhibit of paintings of ancient Egyptian monuments by Joseph Lindon Smith. Members of the staff lectured on art topics to several organizations and as usual furnished information to several hundred visitors and identified many art works submitted.

Freer Gallery of Art.—Accessions to the Freer collections included Egyptian brasswork and crystal; Chinese bronzes, jade, lacquer, and pottery; Persian painting, pottery, and wood carving; Indian painting and sculpture; Japanese sculpture; and Armenian manuscript. The work of the professional staff was devoted to the study of new accessions and objects submitted for purchase and to general research on Oriental and Near East materials. Reports were made on 2,236 objects. The renovation of Whistler's Peacock Room, mentioned in last year's report, was well along toward completion by the end of the year. Visitors to the Gallery totaled 62,801, and 1,626 came to the Gallery offices for special purposes. During the year the Gallery entered into an agreement with the University of Michigan in furtherance of the principles concerning Oriental art contemplated by the will of the late Charles L. Freer.

Bureau of American Ethnology.—The Director of the Bureau, Dr. M. W. Stirling, continued his studies of archeological collections he had made in Panamá. As for the past 4 years, the Associate Director, Dr. F. H. H. Roberts, Jr., directed the operations of the River Basin Surveys, in cooperation with the National Park Service, the Bureau of Reclamation, and the Army Corps of Engineers, and made several field inspection trips. Since the beginning of the program in July 1946, 2,260 archeological sites have been located and recorded, and 484 of these have been recommended for testing or excavation. This year's survey work covered 26 reservoirs located in 8 States and in 5 river basins. At the end of the year excavations were completed or under way in 13 reservoir areas in 9 States. Dr. John P. Harring-

ton continued his study of the grammar of the Abnaki language at Old Town, Maine, and also spent 2 months in Yucatán studying the Maya language. In cooperation with the Canadian Government, Dr. Henry B. Collins, Jr., conducted archeological investigations on Cornwallis Island in the Canadian Arctic, which yielded a large collection of artifacts that throw considerable light on the prehistoric inhabitants of the region. Dr. W. N. Fenton made further studies of the Iroquois, especially at the Tonawanda and Allegany Seneca reservations in western New York, and surveyed considerable pertinent archival material in various libraries.

The Institute of Social Anthropology, an autonomous unit of the Bureau financed by State Department funds, conducted its anthropological teaching and research programs in the following Latin American countries: Brazil, Colombia, México, and Perú. Dr. George M. Foster, Director of the Institute, conducted private investigations in Spain during most of the year. Dr. Gordon R. Willey, senior anthropologist of the Bureau, served as acting director during his absence.

The Bureau issued its annual report, volume 5 of the "Handbook of South American Indians," and one publication of the Institute of Social Anthropology. Ten publications were in press at the close of the year.

International Exchange Service.—The Smithsonian International Exchange Service is the official United States agency for the interchange of governmental, literary, and scientific publications between this country and the other nations of the world. During the past year the Exchange Service handled 1,009,675 packages of such publications, weighing 832,087 pounds, a considerable increase over the previous year. Consignments are now made to all countries except Rumania and China. The number of sets of United States official publications sent abroad in exchange for similar publications of other countries is now 99 (59 full and 40 partial sets). Eighty-three copies of the Federal Register and 87 copies of the Congressional Record are also sent abroad through the Exchange Service.

National Zoological Park.—The zoo collection was enhanced during the year by the addition of a number of animals never before exhibited here. At the end of the fiscal year there were 2,821 specimens in the collection, a decrease of 126 from the previous year. Among the more spectacular accessions were a pair of baby elephants presented by the Government of India, through Prime Minister Nehru and the Indian Embassy in Washington; 3 grizzly bears removed from the Yellowstone National Park and presented by the National Park Service; 2 rare pencil-tailed tree mice from Malaya; and an American black-bear cub, "Smoky," rescued by the Forest Service from a forest fire

in New Mexico. In all, 123 creatures were born or hatched at the Zoo—60 mammals, 17 birds, and 46 reptiles. Both pairs of the Zoo's hybrid bears (female Alaska brown \times male polar) produced cubs. The number of visitors to the Zoo reached the all-time record of 3,437,669, which was 91,619 more than last year. Groups from schools numbered 1,973, aggregating 102,553 individuals, and came from 31 States, some as far away as Maine, Florida, Washington, California, and New Mexico.

Astrophysical Observatory.—Late in the year the Director, L. B. Aldrich, made an inspection trip to the two solar-radiation field stations now operated by the Astrophysical Observatory, one at Table Mountain, Calif., and the other at Montezuma, Chile, and was able to make valuable intercomparisons of methods and results of the research. A significant increase of one-fourth of 1 percent in the radiation emitted by the sun in the two decades from 1925 to 1944 has been calculated from the solar-constant determinations at the Chilean station. The Observatory's work at the temporary observing station at Miami, Fla., for the office of the Quartermaster General, in connection with studies of fabric resistance to solar radiation, were terminated there, and the special equipment was moved to the Table Mountain, Calif., station. Three silver-disk pyrheliometers were constructed under the supervision of W. H. Hoover and furnished at cost to institutions in New Zealand, Venezuela, and Rumania, and two modified Ångström pyrheliometers and one special water-vapor spectroscope were furnished to a meteorological institute in Belgium. The Division of Radiation and Organisms concluded its reorganization and reconstruction of the facilities of its laboratories, which are now equipped with four constant-temperature rooms and with new types of modern instruments and are in first-class condition for photochemical research on plants. Several new lines of research are being inaugurated. The sixth edition of the Smithsonian Meteorological Tables, compiled by Robert J. List, of the United States Weather Bureau, was in press at the close of the year; and the manuscript of the ninth edition of the Physical Tables was nearly completed under the direction of Dr. William E. Forsythe, physicist, of Cleveland, Ohio.

National Air Museum.—The report to Congress on the National Air Museum, required by law, was submitted on March 17, 1950, making recommendations for the acquisition of suitable lands and buildings for the museum. The Advisory Board met on May 24 and gave considerable attention to this report and to the problems involved in advancing the Air Museum's site-procurement and building programs. Several outstanding accessions to the collections were received, including the B-29 superfort *Enola Gay*, the first aircraft to

drop an atomic bomb in warfare; the Stinson SR-10F airplane used by All American Aviation in airmail pick-up service; the *City of Washington*, the Piper Super Cruiser flown around the world in 1947 by Clifford Evans, Jr.; a collection of memorabilia relating to Amelia Earhart; the original Whittle W-1-X turbojet engine; a bust of Wilbur Wright by Oskar J. W. Hansen; and a large collection of aeronautical memorabilia assembled by Mrs. ("Mother") C. A. Tusch, of Berkeley, Calif. The 34 new accessions totaled 465 objects from 31 different sources. Much of the material is being kept at the Museum's storage facility maintained at Park Ridge, Ill., until such time as the projected National Air Museum building is provided.

Canal Zone Biological Area.—Twenty-one scientists, representing a variety of organizations and localities, visited Barro Colorado Island during the year and worked at the laboratory on an equal variety of research projects, and the contributions have added materially to our knowledge of tropical life. High cost of transportation deters many from visiting the island. Since the laboratory was started in 1923, about 660 separate papers have appeared in print dealing with researches made on the area. A recent checklist shows 173 species of vertebrate animals (exclusive of birds) now inhabiting the island. Improvements in facilities completed during the year included the construction of an 11,720-gallon concrete water tank, which has improved the water-supply situation at the station as well as fire protection. Some new building construction is under way. One of the most urgent needs is a dependable electric-power supply. The resident manager continued his long-term termite-resistance tests and studies of host relationships of the fruit-fly population.

PUBLICATIONS

In carrying out the second of the two main functions of the Smithsonian Institution, the diffusion of knowledge, as prescribed by its founder, James Smithson, the Institution issues eight regular series of publications and six others that appear less frequently. All these series, embodying the results of researches of the Smithsonian staff and collaborators, are distributed free to more than a thousand libraries, both here and abroad, as well as to a large list of educational and scientific organizations. The findings of Smithsonian scientists, chiefly in the fields of anthropology, biology, geology, and astrophysics, are therefore made readily available to all through this wide free distribution.

In all, 72 publications appeared under the Smithsonian imprint during the year. Outstanding among these were T. E. Snyder's "Catalog of the Termites of the World," Gordon R. Willey's "Archeology of the Florida Gulf Coast," the eighteenth part of A. C. Bent's

"Life Histories of North American Birds," volume 5 of the "Handbook of South American Indians," Allan R. Holmberg's "Nomads of the Long Bow: The Siriono of Eastern Bolivia," S. H. Oliver's "Catalog of the Automobile and Motorcycle Collection of the Division of Engineering, United States National Museum," and Grace Dunham Guest's "Shiraz Painting in the Sixteenth Century."

The total number of copies of publications in all series distributed during the year was 150,612. A complete list of the year's publications will be found in the report of the chief of the editorial division, appendix 12.

LIBRARY

The Smithsonian library received 53,035 publications during the year, 7,392 of these being gifts from many different donors. Outstanding among the gifts was the fine collection of about 4,000 books and pamphlets on Foraminifera assembled by the late Joseph A. Cushman and bequeathed by him to the Institution. Neil M. Judd donated his personal collection of about 500 books and papers on archeological subjects.

Currently entered were 16,961 periodicals, most of them received in exchange for Smithsonian publications from research institutions and educational organizations throughout the world. The library arranged 344 new exchanges during the year, cataloged 6,822 volumes and pamphlets, added 30,006 cards to catalogs and shelflists, sent 18,719 publications to the Library of Congress, prepared 1,511 volumes for binding, and repaired 1,023 volumes in the Museum.

At the close of the year, the library's holdings totaled 927,037 volumes, more than half of which are housed in the Library of Congress as the Smithsonian Deposit.

Respectfully submitted.

ALEXANDER WETMORE, *Secretary.*

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operations of the United States National Museum for the fiscal year ended June 30, 1950:

COLLECTIONS

Slightly more than 793,300 specimens (approximately 400,000 more than last year) were incorporated into the national collections during the year and were distributed among the six departments as follows: Anthropology, 4,982; zoology, 186,855; botany, 61,983; geology, 530,758; engineering and industries, 2,047; and history, 6,701. Most of the accessions were acquired as gifts from individuals or as transfers from Government departments and agencies. The complete report on the Museum, published as a separate document, includes a detailed list of the year's acquisitions, of which the more important are summarized below. Catalog entries in all departments now total 32,375,597.

Anthropology.—President Harry S. Truman deposited on loan the sacred Scrolls of the Law, hand-lettered in Hebrew on parchment, and a copper Ark finely decorated with biblical inscriptions in silver by skilled craftsmen of the Bezalel School of Arts and Crafts of Jerusalem. These were presented by Chaim Weizmann, first President of Israel, to the President of the United States. Two camel saddles, bridles, and elaborately woven and decorated saddlebags presented by His Majesty, King Ibn Sa'ud of Saudi Arabia, as tokens of friendship to Maj. Gen. C. V. Haynes and Rear Adm. John P. Whitney, were donated to the Museum by the recipients.

Woven fabrics and costumes acquired by the late Gen. John J. Pershing from the Moro, Mandaya, and Bagobo during his tours of duty in the Philippine Islands between 1899 and 1913, and from Peruvian and Bolivian Indians during his visit to South America in 1924-25, were presented by his son, Francis Warren Pershing. Other noteworthy additions were 464 ethnological specimens obtained in northern Australia by Frank M. Setzler, deputy leader of the Commonwealth of Australia-National Geographic Society-Smithsonian Institution Expedition to Arnhem Land; an outfit utilized by the Piaroa Indians of the Río Paria area for snuffing *yopo* (*Piptadenia peregrina*),

presented by Señor José M. Cruxent, Director of the Museo de Ciencias Naturales, Caracas, Venezuela; materials representing the work of Cree Indians living near Hudson Bay and on the plains of Saskatchewan, donated by Copley Amory; 4 carved and painted wooden ancestral figurines from Ngulu Atoll and the island of Woleai in the western Carolines, the gift of N. J. Cummings; and the bequest of Miss Mary W. Maxwell of 235 examples of Oriental and European furniture, textiles, ceramics, and metalwork.

Additions to the archeological collections comprised, among others, a collection of 991 pottery, stone, and other objects from the Neolithic period of northern Honshu, Japan, presented by Maj. Howard A. MacCord, United States Army; 16 gold fishhooks fashioned by the Indians of Columbia, from F. M. Estes; a series of sherds from shell heaps of Panamá, believed to represent the earliest ceramic horizon recognized at present in that region, and excavated by Drs. M. W. Stirling and Gordon R. Willey during the Smithsonian Institution-National Geographic Society Expedition of 1948; and a Basketmaker III pitcher from La Plata County, Colo., donated by E. H. Morris.

Forty-eight more or less complete skeletons from a protohistoric Indian site near Lewes, Del., were presented to the division of physical anthropology by the Sussex Archeological Association.

Zoology.—Zoological specimens from North America, South America, Europe, and Asia, as well as from oceanic areas, were incorporated into the national collections. About 300 monkeys and other arboreal mammals collected by Dr. H. C. Clark and associates in Panamá in the course of yellow-fever investigations carried on by the Gorgas Memorial Laboratory were donated to the division of mammals. Other accessions of importance were 98 mammals from Kuala Lumpur, Selangor, obtained during scrub-typhus investigations by the United States Army Medical Research Unit; 197 mammals from the Brooks Range, northern Alaska, collected by Dr. Robert Rausch, United States Public Health Service; 32 Bolivian mammals received from the Pan American Sanitary Bureau; 295 Costa Rican mammals collected in 1949 by Dr. Henry W. Setzer; 100 mammals from Prince Patrick Island, collected by Charles O. Handley, Jr.; and 36 Japanese mammals, including a series of porpoise skulls from Ford Wilke.

The generous gift of approximately 10,000 skins and 424 skeletons of North American birds by J. A. Weber, of Miami, Fla., represents the largest single accession received by the division of birds in recent years. Income from the W. L. Abbott bequest financed field work in Panamá and Colombia. In Panamá Dr. A. Wetmore and W. M. Perrygo obtained 956 bird skins, 11 skeletons, 3 sets of eggs, and 1 nest; and in Colombia, M. A. Carriker, Jr., collected 2,546 bird skins and 3 sets of eggs. The E. J. Brown bequest provided funds for the purchase of

74 skins of Hungarian birds, and with other private funds 344 bird skins from British Columbia were purchased. From Herbert L. Stoddard, the division of birds received 158 skins of birds taken in Georgia.

By exchange, the division of reptiles and amphibians received from the Museum of Comparative Zoology 94 amphibians from the state of São Paulo, Brazil. As a gift from Cornell University, the division acquired 141 specimens from Venezuela. Other accessions worthy of note were the gift of 148 reptiles, including a series of water snakes from Ohio, by John T. Wood, and 24 blind cave salamanders (*Typhlotriton spelaeus*) from Smellin's Cave near Ozark, Mo., presented by Dr. C. G. Goodchild.

The Fish and Wildlife Service transferred approximately 4,500 fishes taken in the course of shrimp investigations in the Gulf of Mexico by the crew of the *Pelican*. Other gifts received during the year included a specimen of a rare ribbonfish (*Lophotus lacepedei*) taken at Clearwater, Fla., donated by Dr. Coleman J. Goin; 517 Mexican fishes given by Gen. T. D. White, United States Air Forces, accompanied by color sketches made by Mrs. White; and 80 fishes from Spencer Tinker, of the Waikiki Aquarium, Hawaii. Types and paratypes of a number of fishes were acquired by exchange or donation from several institutions.

Several outstanding gifts came to the division of insects. Among these were a collection of 5,000 British tortricid moths presented by the British Museum (Natural History); about 15,000 British Microlepidoptera, a gift from Norman D. Riley, head keeper of insects, British Museum (Natural History); and an extensive collection of 2-winged flies donated by John R. Malloch. About 10,500 beetles, mostly representing the families Carabidae and Pselaphidae, were received as a bequest from Alan S. Nicolay.

As a transfer from the Office of Naval Research the Museum acquired a collection of 2,571 marine invertebrates made by Prof. and Mrs. G. E. MacGinitie at the Arctic Research Laboratory, Point Barrow, Alaska. Nearly 4,000 miscellaneous invertebrates, obtained off the coast of Labrador by David C. Nutt during the cruise of the schooner *Blue Dolphin* under the auspices of the Arctic Institute of North America, were presented to the division of marine invertebrates. Among other noteworthy gifts of collections, including types, were: 541 shrimps and other marine invertebrates obtained during the "Crossroads" Expedition to the Marshall Islands, from Dr. Martin W. Johnson, Scripps Institution of Oceanography; more than 100 isopods from Pacific Marine Station, College of the Pacific and the University of California, through Robert J. Menzies; about 700 marine arthropods, taken off the coasts of North and South Carolina, from

Prof. A. S. Pearse, Duke University; 137 echiuroid and sipunculoid worms and 10 flatworms from Dr. W. K. Fisher; and more than 100 Indian amphipods from Dr. K. Nagappan Nayar, of Madras, India.

As gifts, the division of mollusks received a collection approximating 4,000 specimens, largely North American Sphaeriidae, from Leslie Hubricht; 300 marine mollusks from Biak Island, Netherlands East Indies; and holotypes, paratypes, and topotypes from a number of specialists. By transfer, about 500 mollusks collected by Dr. Preston E. Cloud, Jr., on Saipan came to the Museum from the Geological Survey; approximately 5,000 marine shells from Panamá were received from the Fish and Wildlife Service through Dr. Paul S. Galtsoff; and from the Smithsonian Institution 621 land and fresh-water mollusks from Perú purchased through the income of the Frances Lea Chamberlain fund.

The most noteworthy accession acquired by the division of echinoderms comprised 400 specimens dredged from the deep waters of the North Atlantic Ocean by the Woods Hole Oceanographic Institution's vessel *Atlantis*.

Botany.—H. A. Allard collected 5,577 plants for the National Herbarium in northeastern Perú, and Associate Curator E. H. Walker obtained 2,282 plants in New Zealand. As exchanges, the National Herbarium received 19,276 specimens, of which 4,175 were transmitted by the University of California, 1,027 from Eritrea were shipped by the University of Florence, and 762 from islands in the Pacific Ocean were forwarded by the Bernice P. Bishop Museum. Dr. John Gossweiler, of Angola, presented through the Department of State 645 plant specimens from Portuguese West Africa, and Dr. C. M. Rogers, of Wayne University, Detroit, donated 980 specimens from the Mesa de Maya region of the southwestern United States. The Escuela Agrícola Panamericana, Tegucigalpa, Honduras, forwarded 965 plants, partly on an exchange basis and the remainder as a gift. By purchase, 1,596 plant specimens from Colombia were acquired from Kjell von Sneidern, and by transfer from the Division of Rubber Plant Investigations, Department of Agriculture, 2,098 plants, collected for the most part by Dr. Richard E. Schultes in the eastern lowlands of Colombia, were added to the collections.

Geology.—Twenty-four minerals hitherto unrepresented were added to the mineralogical collections, of which seven were received as gifts, eight were acquired as exchanges, and nine came as transfers from the Geological Survey. The Kegel collection of fine crystallized secondary copper and lead minerals from Tsumeb, Southwest Africa, comprising approximately 900 specimens and including many of the best-known examples of azurite, malachite, cerussite, anglesite, vanadinite, and mimetite, is considered to be the most important acces-

sion ever purchased under the Roebling fund. Included among the additions to the Canfield collection were a very fine columbite crystal from North Carolina, a large specimen of native lead with pyrochroite from Sweden, a striking example of rutilated quartz from Brazil, and a group of large wulfenite crystals from Arizona. An outstanding addition to the gem collection consists of 41 pieces made up largely of strands of beads of a variety of gem materials, as well as some very fine cut amethysts, a bequest of Mrs. Edna Ward Capps. In addition to a number of gems received as gifts, an unusual tourmaline cat's-eye weighing 53.20 carats was purchased under the Chamberlain fund for the gem collection. Dr. Stuart H. Perry continued his interest in the meteorite collection by donating two stony meteorites weighing 8.4 kilograms and 502 grams, recently found at Kearney, Nebr. Sections of other meteorites were received from the Georgia Department of Mines, Mining, and Geology and from the Institute for Nuclear Studies of the University of Chicago through Dr. Harrison Brown. By exchange, portions of five Spanish meteorites were acquired from the Museo Nacional de Ciencias Naturales of Madrid, Spain.

Gifts, exchanges, transfers, and purchases added many genera and species not previously represented in the collections of fossil invertebrates. As gifts, the Museum received 500 fresh-water invertebrate fossils of the Pliocene Truckee formation from Daniel I. Axelrod; approximately 2,600 Ordovician fossils from O. C. Cole; 45 Turkish Jurassic fossils from G. H. Cornelius; 150 invertebrate fossils from Wales, collected by Dr. John P. Marble; 150 Italian Triassic invertebrates from Dr. Franco Rasetti; and 500 Paleozoic, Mesozoic, and Cenozoic invertebrates from Tunisia, Algeria, and the Sahara Desert from Maurice H. Wallace. Types of corals, Foraminifera, and Carboniferous fossils were included in the accessions.

Several hundred Ordovician, Mississippian, and Pennsylvanian crinoids were purchased under the Springer fund from Harrell L. Strimple.

By the bequest of the late Dr. Joseph A. Cushman, the Museum acquired his library and collection of Foraminifera comprising at least 150,000 slides and including about 13,000 type and figured specimens. The Vaughan collection of larger Foraminifera, aggregating about 25,000 specimens, as well as the smaller Foraminifera formerly housed in the Cushman laboratory at Sharon, Mass., 1,275 type and figured Jurassic Foraminifera from Montana, Wyoming, and South Dakota, 147 type specimens of Mesozoic and Cenozoic Foraminifera from Naval Petroleum Reserve No. 4 in northern Alaska, and 653 Silurian brachiopods from southeastern Alaska were received as transfers from the Geological Survey. Through funds provided by the Walcott bequest, the Museum purchased the Renfro fossil invertebrate collec-

tion comprising about 250,000 specimens from the Pennsylvanian of Jack County, Tex., and the Cretaceous in the vicinity of Fort Worth, Tex. Field work financed by the same fund resulted in the collection of about 15,000 Paleozoic invertebrates by Dr. G. A. Cooper and W. T. Allen in the Midwest, 500 Ordovician fossils by Dr. Cooper in New York and Pennsylvania, and approximately 3,000 Lower Cretaceous fossils by Dr. A. R. Loeblich, Jr., and W. T. Allen in southern Oklahoma and northern Texas.

An excellent series of fossil mammals from the Paleocene of the San Juan Basin, New Mexico, and the lower Eocene of western Wyoming, including the condylarth *Meniscotherium* and the earliest titanothere, *Lambdotherium*, were obtained by Dr. C. Lewis Gazin. Skeletal remains of the giant ground sloth *Megatherium* and associated elements of the Pleistocene fauna were excavated by Dr. Gazin in Herrera Province, western Panamá. Dr. David H. Dunkle assembled an unusual collection of Jurassic fossil fishes in the Pinar del Río region of western Cuba. Skulls of two distinct types of mosasaurs, collected by Dr. T. E. White in the Cretaceous of Texas, were transferred by the Smithsonian River Basin Surveys.

Engineering and industries.—The Dan River Mills, Inc., presented exhibition units illustrating the operation of a textile-finishing mill, the development of a fabric design, and the production of a wrinkle-shed finish. A hydraulic duplex pump, the first pumping engine of the Washington (D. C.) aqueduct system, was transferred by the District of Columbia through the Board of Commissioners.

Two prints by Stanley William Hayter, one titled "Cronos," an engraving and soft-ground etching, and the other titled "Palimpsest," a soft-ground etching printed in three colors, as well as a lift-ground aquatint named "La Faute," by Jacques Villan, were purchased for graphic arts under the Dahlgreen fund. Fifty-one examples of the work of the photographer Victor Prevost, who pioneered in the use of waxed-paper negatives in the United States, were presented by Melville Rosch. A Renfax synchronizer, early sound equipment used prior to the invention of sound on film, was received from Ralph S. Koser. A graphic portrayal of the development and use of sutures in early times is shown in the exhibit "Sutures in Ancient Surgery" donated by Davis & Geck, Inc.

History.—A silver-filigree basket reputed to have belonged to Napoleon and received as a bequest from Miss Bessie J. Kibbey is worthy of notice.

Two outstanding ship models, one of them a small-scale reproduction of the U. S. S. *Yorktown* (CV-5) with a squadron of planes on the flight deck, and the other a remarkably fine scale model of the U. S. S. *Washington* (later *Seattle*), were transferred by the Department of the

Navy. A series of military uniforms of the period of World War II were received as a transfer from the Department of the Army. The Bureau of Engraving and Printing deposited two specimen sets of current United States paper money and Federal Reserve notes in denominations from \$1 to \$10,000.

A portfolio of 107 de-luxe proofs and stamps of the Principality of Monaco, presented by Prince Rainier III to the Economic Cooperation Administration, were received as a transfer, and the same agency also forwarded a collection of Italian stamps issued in commemoration of the European Recovery Program, a gift of the Government of Italy. Recently issued foreign stamps totaling 2,964 in number were transferred by the Universal Postal Union.

EXPLORATION AND FIELD WORK

During the first half of the fiscal year, Dr. Waldo R. Wedel, at that time associate curator of archeology, was detailed to the River Basin Surveys, Bureau of American Ethnology, to supervise field and laboratory operations in the Missouri Valley.

Under the W. L. Abbott fund, M. A. Carriker, Jr., during the present season continued investigations of the bird life of northern Colombia, making collections in the lower Atrato Basin. He entered the area from Medellín, proceeding by air to Turbo, then moving by boat to stations on each side of the Gulf of Urabá. His investigations continued along the lower Atrato, in part near the Panamanian frontier, extending finally into more elevated regions above Frontino. Examples of more than 500 species of birds were obtained in this interesting region where there is union between the forms of life found in eastern Panamá and those of northwestern South America.

Dr. Alexander Wetmore, with Watson M. Perrygo as assistant, was again in the field in eastern Panamá from the middle of February to the beginning of April, their work being concerned with the collection and distribution of birds. Through the friendly assistance of Brig. Gen. R. Beam, commanding officer, Albrook Air Base, and of Lt. Col. M. E. Potter, director of personnel services, in providing transportation by water and other facilities, a base was established in Chimán on the Pacific coast about 90 miles east of Panamá City. The party worked first on the lower portion of the Río Chimán and then moved in cayucos to the head of tidewater on the Río Majé. From here the naturalists proceeded on foot with porters to the lower elevations of Cerro Chucantí in the Serranía de Majé. The region covered was in an extensive area of virgin forest without human inhabitants, beyond the limit of navigation by canoe. An excellent collection of birds was obtained in a region that so far as known has not been visited previously by naturalists.

Under a cooperative arrangement with the United States Weather Bureau, Charles O. Handley, Jr., was detailed to make natural-history collections on Prince Patrick Island in the Canadian Arctic Archipelago. As the year closed, the curator of birds, Dr. Herbert Friedmann, was en route to South Africa and southern Rhodesia to study the habits of the parasitic honey-guides and weaverbirds, having received grants for the purpose from the American Philosophical Society and the John Simon Guggenheim Memorial Foundation.

Associate Curator Paul L. Illg assembled data on the life histories and ecology of commensal copepods at the University of Washington oceanographic laboratories at Friday Harbor. Dr. J. P. E. Morrison, associate curator of mollusks, made a short field study of mollusks inhabiting the salt marshes on the eastern shore of Maryland. Assistant Curator R. Tucker Abbott was detailed, at the request of the Pacific Science Board, National Research Council, to conduct field studies in Kenya and Tanganyika, East Africa, for the purpose of obtaining carnivorous snails and transporting them to the Trust Territories of the Pacific, a part of the program planned for the control of the destructive giant snail in that area.

W. L. Brown, chief exhibits preparator, visited South Carolina and Wyoming to procure background materials required for the completion and installation of the Virginia-deer and pronghorn-antelope exhibition groups in the North American mammal hall.

Head Curator E. P. Killip and Curator Jason R. Swallen were engaged for 3 weeks in botanical field studies on Big Pine Key, Fla., collecting specimens and making observations on the distribution of plant life. At the request of the Department of Agriculture, Mr. Swallen was detailed to the Great Plains Field Station at Mandan, N. Dak., to review experimental work now being conducted there on the crested wheatgrass, and to the Texas Research Foundation at Kingsville, Tex., to complete a survey of the grasses of that region. Dr. George A. Llano, associate curator of cryptogams, made extensive collections of lichens under the auspices of the Arctic Institute of North America after proceeding to the Arctic Research Laboratory at Point Barrow, Alaska, where he was provided with transportation to Wainwright, Umiat on the Colville River, Anaktuvuk Pass in the Brooks Range, and Anchorage. On the return trip Dr. Llano made collections on several islands in the Aleutian Chain. Associate Curator Paul S. Conger, division of cryptogams, was engaged in studying marine diatoms for 2 months at the Chesapeake Biological Laboratory, Solomons Island, Md. Dr. F. A. McClure, research associate in grasses, continued with his studies of the bamboos in the West Indies, Central America, and South America.

At the request of the Instituto de Antropología e Historia, Dr. W. F. Foshag, head curator of geology, on detail from the National Museum, traveled to Guatemala and devoted 3 months to a study of the mineralogical composition of Meso-American archeological jade objects in the Museo de Antropología at Guatemala City, the well-known Rossbach collection in the Municipal Museum at Chichicastenango, the Robles collection at Quetzaltenango, and the Nottlebahn collections. As part of a project relating to the mineralogy and geochemistry of saline mineral deposits, Dr. George S. Switzer spent 3 months investigating the origin and occurrence of rare sulfate minerals at The Geysers and Island Mountain, Calif.

Paleontological field work financed from the income of the Walcott bequest brought new materials from Panamá, Cuba, and the United States to the collections. The four field parties studying problems in invertebrate paleontology in the United States comprised the following: Dr. G. A. Cooper, W. T. Allen, and Alwyn Williams, visiting Commonwealth Fellow from Wales, collected lower Middle Ordovician brachiopods at various localities in Michigan, Minnesota, Wisconsin, Tennessee, Iowa, Missouri, Oklahoma, Texas, and New Mexico; Dr. A. R. Loeblich and W. T. Allen carried on field investigations in the Lower Cretaceous of Oklahoma and Texas; lower Middle Ordovician strata in Pennsylvania and New York were examined by Dr. Cooper and Mr. Williams; and David Nicol visited Upper Cretaceous and Tertiary beds in North Carolina and Virginia. Dr. C. L. Gazin, curator of vertebrate paleontology, assisted by F. L. Pearce, searched for Paleocene mammals in the Puerco and Torrejon horizons in the San Juan Basin of New Mexico, and later in the season transferred the field work to the Lower Eocene Knight formation in the vicinity of Big Piney and LaBarge in western Wyoming. At the invitation of the Museo Nacional de Panamá and with the cooperation of the Panamanian Government, Dr. Gazin, with Dr. T. E. White as assistant, proceeded to Herrera Province where they achieved considerable success in the excavation of remains of the giant ground sloth *Megatherium*. A part of this collection will eventually be returned to Panamá for display. Associate Curator David H. Dunkle was highly successful in obtaining an excellent series of fossil fish and ammonites from the Jurassic Jagua formation in the Piñar del Río region of western Cuba.

PUBLICATIONS

During the fiscal year 1949-50, 29 publications were issued: 1 Annual Report, 2 in the Bulletin series, 22 in the Proceedings, and 4 numbers of the Contributions from the United States National Herbarium. A list of these is given in the complete report on Smithsonian publications,

appendix 12. Special mention is made of the eighteenth volume of A. C. Bent's Life Histories of North American Birds entitled "Life Histories of North American Wagtails, Shrikes, Vireos, and Their Allies," and a "Catalog of the Automobile and Motorcycle Collection of the Division of Engineering, United States National Museum," by S. H. Oliver.

The distribution of volumes and separates to libraries and other institutions and to individuals aggregated 57,938 copies.

CHANGES IN ORGANIZATION

After almost 38 years of continuous service, Neil M. Judd retired from active duty as curator of the division of archeology on December 31, 1949, and to this vacancy, Dr. Waldo R. Wedel, who had served as associate curator in the same division, was promoted on January 1, 1950.

Dr. Preston E. Cloud, Jr., chief of paleontology and stratigraphy branch, United States Geological Survey, and Dr. Roland W. Brown, geologist in the same service, were given honorary appointments on November 9, 1949, as custodians of Paleozoic fossils and of Mesozoic and Cenozoic plants, respectively.

Respectfully submitted.

REMINGTON KELLOGG, *Director.*

Dr. A. WETMORE,

Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit, on behalf of the Board of Trustees, the thirteenth annual report of the National Gallery of Art, for the fiscal year ended June 30, 1950. This report is made pursuant to the provisions of section 5 (d) of Public Resolution No. 14, Seventy-fifth Congress, first session, approved March 24, 1937 (50 Stat. 51).

ORGANIZATION

The statutory members of the Board of Trustees of the National Gallery of Art are the Chief Justice of the United States, the Secretary of State, the Secretary of the Treasury, and the Secretary of the Smithsonian Institution, ex officio. The five general trustees continuing in office during the fiscal year ended June 30, 1950, were Samuel H. Kress, Ferdinand Lamot Belin, Duncan Phillips, Chester Dale, and Paul Mellon. The Board of Trustees held its annual meeting on May 4, 1950. Samuel H. Kress was reelected President and Ferdinand Lamot Belin, Vice President, to serve for the ensuing year. Donald D. Shepard continued to serve during the year as Adviser to the Board. All the executive officers of the Gallery continued in office during the year.

The three standing committees of the Board, as constituted at the annual meeting May 4, 1950, were as follows:

EXECUTIVE COMMITTEE

Chief Justice of the United States, ex officio, Fred M. Vinson, Chairman.
Samuel H. Kress, Vice Chairman.
Ferdinand Lamot Belin.
Secretary of the Smithsonian Institution, Dr. Alexander Wetmore.
Paul Mellon.

FINANCE COMMITTEE

Secretary of the Treasury, ex officio, John W. Snyder, Chairman.
Samuel H. Kress, Vice Chairman.
Ferdinand Lamot Belin.
Chester Dale.
Paul Mellon.

ACQUISITIONS COMMITTEE

Samuel H. Kress, Chairman.
 Ferdinand Lammot Belin, Vice Chairman.
 Duncan Phillips.
 Chester Dale.
 David E. Finley, ex officio.

Perry B. Cott was appointed Assistant Chief Curator on September 1, 1949, to fill the vacancy created by the resignation of Charles Seymour, Jr., which was effective as of August 15, 1949. Mr. Seymour resigned to become associated with Yale University.

APPROPRIATIONS

For the fiscal year ended June 30, 1950, the Congress of the United States appropriated for the National Gallery of Art the sum of \$1,114,700 to be used for salaries and expenses in the operation and upkeep of the Gallery, the protection and care of works of art acquired by the Board of Trustees, and all administrative expenses incident thereto as authorized by section 4 (a) of Public Resolution No. 14, Seventy-fifth Congress, first session, approved March 24, 1937 (50 Stat. 51). This sum includes the regular appropriation of \$1,087,700 and a supplemental appropriation of \$27,000. The supplemental appropriation was necessitated by the Classification Act of 1949, Public Law 429, Eighty-first Congress, effective October 30, 1949, which gave salary advancement to Government employees.

From these appropriations the following expenditures and encumbrances were incurred:

Personal services.....	\$989, 600. 00
Printing and reproduction.....	5, 535. 98
Supplies, equipment, etc.....	119, 498. 07
Unobligated balance.....	65. 95
Total.....	1, 114, 700. 00

In addition to these appropriations the Gallery received from the National Capital Sesquicentennial Commission the sum of \$25,000 for expenses in connection with the exhibition called "Makers of History in Washington, 1800-1950." The period of the exhibition was from June 29, 1950, to November 19, 1950. As of June 30, 1950, the sum of \$13,237.19 had been spent or obligated, leaving a balance of \$11,762.81 for operations during the fiscal year 1951.

ATTENDANCE

During the fiscal year 1950 there were 2,187,293 visitors to the Gallery, an increase of 657,725 over the attendance for 1949. The

average daily number of visitors was 6,025. From March 17, 1941, the day the National Gallery of Art was opened to the public, to June 30, 1950, the number of visitors totaled 17,258,269.

ACCESSIONS

There were 2,354 accessions by the National Gallery of Art, as gifts, loans, or deposits, during the fiscal year. Most of the paintings and a number of the prints were placed on exhibition.

PAINTINGS

On December 6, 1949, the Board of Trustees approved the purchase of the painting "The Skater," by Gilbert Stuart, with funds of the Gallery.

The Board of Trustees on October 18, 1949, accepted four paintings: Self-portrait of Judith Leyster from Mr. and Mrs. Robert Woods Bliss; "Colonel Pocklington and his Sisters," by Stubbs, from Mrs. Charles S. Carstairs; "Enthroned Madonna and Child," Byzantine thirteenth century, from Mrs. Otto Kahn; and "Young Woman in White," by Robert Henri, from Miss Violet Organ.

DECORATIVE ARTS

The Board of Trustees accepted from Lewis Einstein on December 6, 1949, a seventeenth-century Brussels tapestry entitled "America."

PRINTS AND DRAWINGS

On October 18, 1949, the Board of Trustees accepted from Miss Margaret McCormick a drawing, "Head of an Old Man," attributed to Legros. The Board on December 6, 1949, accepted a woodcut, "Men with Boat on Shore of Ocean," by A. Lepère, from George Matthew Adams. At the same time the Board approved the addition of four Legros drawings and four Legros etchings to the gift by George Matthew Adams of prints and drawings by Legros, and other works of art. On May 4, 1950, the Board accepted 3 prints, "Wet" and "Seaward Skerries," by Zorn, and "Limeburner," by Whistler, from Walter L. Bogert; 142 prints and drawings from Lessing J. Rosenwald, to be added to his gift to the Gallery; and 51 seventeenth-century Dutch prints from John Thacher in memory of Charles Hoyt. On the same date the Board also approved the addition of three Legros drawings and five Legros etchings to the gift by George Matthew Adams of prints and drawings by Legros, and other works of art.

EXCHANGE OF WORKS OF ART

The Board of Trustees on October 18, 1949, accepted the offer of Lessing J. Rosenwald to exchange the engraving "The Madonna on the Half-Moon," by Hans Sebald Beham, for a superior impression of the same work; and on December 6, 1949, the Board also accepted Mr. Rosenwald's offer to exchange nine prints from the Rosenwald Collection for superior impressions of like prints.

WORKS OF ART ON LOAN

During the fiscal year 1950 the following works of art were received on loan by the National Gallery of Art:

<i>From</i>	<i>Artist</i>
Copley Amory, Washington, D. C.:	
Elizabeth Copley (Mrs. Gardiner Greene).....	Copley.
Self-portrait.....	Copley.
Mrs. Albert J. Beveridge, Beverly Farms, Mass.:	
Madame Dietz-Monin.....	Degas.
C. S. Gulbenkian, Lisbon, Portugal:	
Cupid and the Graces.....	Boucher.
The Annunciation.....	Dierick Bouts.
The Virgin and Two Donors Adoring the Child.....	Carpaccio.
A Sacra Conversazione (The Rest on the Flight).....	Cima.
A Road at Ville-d'Avray.....	Corot.
The Bridge at Mantes.....	Corot.
Venice from the Dogana.....	Corot.
L'Homme et le Pantin.....	Degas.
Self-portrait.....	Degas.
A Fete at Rambouillet.....	Fragonard.
Baptism of Christ.....	Francia.
Mrs. Lowndes-Stone.....	Gainsborough.
Portrait of a Young Woman.....	Ghirlandaio.
View of Mira on the Brenta.....	Guardi.
S. Pietro di Castello, Venice.....	Guardi.
A Regatta on the Grand Canal.....	Guardi.
A Fete on the Piazza di San Marco.....	Guardi.
Portrait of Sara Andriesdr. Hessix.....	Hals.
Frances Beresford.....	Hoppner.
A Fete Galante.....	Lancret.
Mademoiselle Sallé.....	La Tour.
Portrait of Baron Duval d'Espinoy (Man with a Snuff Box).....	La Tour.
Lady Conyngham.....	Lawrence.
The Astronomer.....	L'Epicie.
Portrait of a Man.....	L'Epicie.
The Presentation in the Temple (Reverse: Stigma- tization of St. Francis).....	Stefan Lochner.
The Boy with the Cherries.....	Manet.
The Boy Blowing Bubbles.....	Manet.
The Break-Up of the Ice.....	Monet.

<i>From</i>	<i>Artist</i>
C. S. Gulbenkian, Lisbon, Portugal—Continued	
Still Life.....	Monet.
Portrait of Tocqué.....	Nattier.
Portrait of Madame de la Porte.....	Nattier.
Pallas Athene.....	Rembrandt.
An Old Man Seated.....	Rembrandt.
Madame Claude Monet Lying on a Sofa.....	Renoir.
Felling the Trees at Versailles, 1774/5.....	Hubert Robert.
Felling the Trees at Versailles, 1774/5.....	Hubert Robert.
Portrait of Miss Constable.....	Romney.
Portrait of a Young Woman.....	Rubens.
Flight into Egypt.....	Rubens.
Portrait of a Man.....	Van Dyck.
Two Ming vases, black.	
One lapis-lazuli ewer.	
William H. Jeffreys, Bethesda, Md.:	
The Jeffreys Family.....	Hogarth.
Samuel H. Kress Foundation, New York, N. Y.:	
1,289 bronzes from the Dreyfus Collection.	
Robert Woods Bliss, Washington, D. C.:	
22 objects of Pre-Columbian art.	

LOANED WORKS OF ART RETURNED

The following works of art on loan were returned during the fiscal year 1950:

<i>To</i>	<i>Artist</i>
The Italian Government:	
A marble statue of David.....	Michelangelo.
Stanley Mortimer, Jr., New York, N. Y.:	
Madonna and Child.....	School of Ghiberti.
Paul Mellon, Upperville, Va.:	
Six books of drawings and prints.....	Blake.
James Hazen Hyde, New York, N. Y.:	
Louis XVI tapestry-covered sofa.	
Robert Woods Bliss, Washington, D. C.:	
One object of Pre-Columbian art.	

WORKS OF ART LENT

During the fiscal year 1950 the Gallery lent the following works of art for exhibition purposes:

<i>To</i>	<i>Artist</i>
Amherst College, Department of Fine Arts, Amherst, Mass.:	
Self-portrait.....	Benjamin West.
Columbia Museum of Art, Columbia, S. C.:	
George Washington (Vaughan-Sinclair).....	Gilbert Stuart.
Self-portrait.....	Benjamin West.
Ann Biddle Hopkinson.....	Thomas Sully.

<i>To</i>	<i>Artist</i>
Columbia Museum of Art, Columbia, S. C.—Continued	
Francis Hopkinson.....	Thomas Sully.
Alexander Hamilton.....	John Trumbull.
William Rickart.....	Gilbert Stuart.
Henry Laurens.....	J. S. Copley.
Pocahontas.....	British School.
Andrew Jackson.....	Ralph E. W. Earl.
John Philip de Haas.....	Charles Willson Peale.
Henry Clay.....	John James Audubon.
General William Moultrie.....	Charles Willson Peale.
Williamina Moore.....	Robert Feke.
Mary Walton Morris.....	John Wollaston.
Jane Browne.....	J. S. Copley.
William S. Mount.....	Charles Loring Elliott.
Josias Allston.....	Jeremiah Theus.
Matilda Caroline Cruger.....	Gilbert Stuart.
George Pollock.....	Gilbert Stuart.
Mrs. George Pollock.....	Gilbert Stuart.
Robert Thew.....	Gilbert Stuart.
Luke White.....	Gilbert Stuart.
Corcoran Gallery of Art, Washington, D. C.:	
Pocahontas.....	British School.
Abraham Lincoln.....	Healy.
The Lackawanna Valley.....	Inness.
Four Arts Gallery, Palm Beach, Fla.:	
George Washington (Vaughan-Sinclair).....	Gilbert Stuart.
Self-portrait.....	Benjamin West.
Alexander Hamilton.....	John Trumbull.
Ann Biddle Hopkinson.....	Thomas Sully.
Francis Hopkinson.....	Thomas Sully.
Los Angeles County Museum, Los Angeles, Calif.:	
Indian hunting rug.	
Montreal Museum of Fine Arts, Montreal, Canada:	
Two drawings:	
La Petite Loge.....	Moreau le Jeune.
Tête-à-tête.....	Boucher.
Art Gallery of Toronto, Toronto, Canada:	
Mrs. Richard Yates.....	Gilbert Stuart.
Virginia Museum of Fine Arts, Richmond, Va.:	
James Buchanan.....	Healy.
Abraham Lincoln.....	Healy.
The White House, Washington, D. C.:	
Andrew Jackson.....	Sully.

EXHIBITIONS

During the fiscal year 1950 the following exhibitions were held at the National Gallery of Art:

Indigenous Art of the Americas. Lent by Robert Woods Bliss for an indefinite period to the National Gallery of Art for exhibition. Reopened with changes May 23, 1948.

Gulbenkian Collection of Egyptian Sculpture. Lent by C. S. Gulbenkian for an indefinite period to the National Gallery of Art for exhibition. Opened January 30, 1949.

Gulbenkian Collection of Eighteenth Century French Objects. Lent by C. S. Gulbenkian for an indefinite period to the National Gallery of Art for exhibition. Opened February 20, 1949.

R. Horace Gallatin Collection. Exhibition of prints bequeathed to the National Gallery of Art by Mr. Gallatin. Continued from previous fiscal year through July 25, 1949.

South African Art. Exhibition of contemporary South African paintings, drawings, and sculptures sponsored by the Government of the Union of South Africa. July 31 to September 5, 1949.

R. Horace Gallatin Collection. Exhibition of the same prints mentioned above. September 10 to October 17, 1949.

Art Treasures from the Vienna Collections. Exhibition, lent by the Austrian Government, of paintings, sculptures, miniatures, Greek and Roman antiquities, ivories, works of goldsmiths and silversmiths, rock crystal and precious stones, jewels, arms and armor, a clock, and tapestries. November 20, 1949, to January 22, 1950.

American Paintings from the Collection of the National Gallery of Art. February 5 to April 2, 1950.

Rosenwald Collection. Exhibition of recent accessions of prints and drawings. Opened April 9, 1950.

Makers of History in Washington, 1800-1950. Exhibition celebrating the sesquicentennial of the establishment of the Federal Government in the City of Washington. Opened June 29, 1950.

The following exhibitions were displayed in the cafeteria corridor of the Gallery during the fiscal year 1950:

Prints by Adriaen van Ostade. Rosenwald and Addie Burr Clark Collections. Continued from previous fiscal year through August 21, 1949.

Nineteenth-century French Prints. Rosenwald and George Matthew Adams Collections. August 23 to November 27, 1949.

Exhibition of Rowlandson Prints. Rosenwald Collection. November 28, 1949, to February 27, 1950.

Prints by Muirhead Bone, David Y. Cameron, and James McBey. Rosenwald Collection and gift of Miss Elisabeth Achelis. February 28 to May 14, 1950.

Index of American Design. Water-color renderings. Opened May 15, 1950.

TRAVELING EXHIBITIONS

Rosenwald Collection.—Special exhibitions of prints from the Rosenwald Collection were circulated to the following places during the fiscal year:

Kenneth Taylor Galleries, Nantucket, Mass.:

35 Rowlandson prints.

July–September 1949.

Milwaukee Art Institute, Milwaukee, Wis.:

42 prints.

November–December 1949.

Smith College Museum of Art, Northampton, Mass.:

10 prints.

December 1949.

Minneapolis Institute of Fine Arts, Minneapolis, Minn.:

8 Gauguin prints.

April 1950.

The Royal Ontario Museum of Archaeology, Toronto, Canada:

4 miniatures.

April–May 1950.

Montreal Museum of Fine Arts, Montreal, Canada:

1 Fragonard drawing.

April–May 1950.

Philadelphia Museum of Art, Philadelphia, Pa.:

23 prints.

September–December 1949.

Index of American Design.—During the fiscal year 1950 exhibitions from this collection were shown at the following places:

Arnot Art Gallery, Elmira, N. Y.

Society of Fine Arts, Wilmington, Del.

Wustum Museum of Fine Arts, Racine, Wis.

Spelman College, Atlanta, Ga.

Kenneth Taylor Galleries, Nantucket, Mass.

St. Paul Public Library, St. Paul, Minn.

Public Schools of Springfield, Springfield, Mass.

Museum of Art, University of Oklahoma, Norman, Okla.

Dickinson College, Carlisle, Pa.

Worcester Art Museum, Worcester, Mass.

Montgomery Blair High School and Leland Junior High School, Maryland (adult classes).

New York State Historical Association, Cooperstown, N. Y.

Manchester Historic Association, Manchester, N. H.

University of Oklahoma, Norman, Okla.

Cooper Union Museum, New York, N. Y.

Brooklyn Museum, Brooklyn, N. Y.

Wm. Rockhill Nelson Gallery, Kansas City, Mo.

Congressional Women's Club, Washington, D. C.

Chicago Historical Society, Chicago, Ill.

Manchester Historic Association, Manchester, N. H.

University of Maine, Orono, Maine.

Wiscasset Library, Wiscasset, Maine.
Sweat Memorial Art Museum, Portland, Maine.
Brick Store Museum, Kennebunk, Maine.
John Herron Art Institute, Indianapolis, Ind.
Library of Congress, Washington, D. C.
Wilmington College, Wilmington, Ohio.
Edinburg Regional College, Edinburg, Tex.
Western Reserve Historical Society, Cleveland, Ohio.
Tate Gallery, London, England.
Old Sturbridge Village, Sturbridge, Mass.
The Downtown Gallery, New York, N. Y.
State Exposition Building, Los Angeles, Calif.
State Capitol, Sacramento, Calif.

CURATORIAL ACTIVITIES

The Curatorial Department accessioned 218 new gifts to the Gallery during the fiscal year. Advice was given in the case of 265 works of art brought to the Gallery for opinion, and 34 visits to other collections were made by members of the staff in connection with proffered works of art. About 300 paintings were studied and considered for possible acquisition. About 1,000 inquiries requiring research were answered. During the year, 11 individual lectures were given by members of the curatorial staff, both at the Gallery and elsewhere. In addition, Miss Elizabeth Mongan conducted special weekly classes at Alverthorpe, Jenkintown, Pa., for students from Beaver College; Perry B. Cott participated in the oral examination of a candidate for a master's degree in art from Indiana University and prepared an examination for two students at American University for their master's degrees in art; and Charles M. Richards gave two courses in art history under the auspices of the Department of Agriculture. Mr. Cott also represented the National Gallery at a conference at the Peabody Museum, Salem, Mass., and at a conference at the National Academy of Design in New York; and Mr. Richards presented a paper and a report to the American Association of Museums meeting at Colorado Springs, Colo.

Special installations were prepared for the Art Treasures from the Vienna Collections, lent by the Austrian Government, and for the Sesquicentennial exhibition, "Makers of History in Washington, 1800-1950."

Over 20,000 photographs were acquired this year from European museums and other sources, and these are being cataloged and filed in the George Martin Richter Archives.

RESTORATION AND REPAIR OF WORKS OF ART

Necessary restoration and repair of works of art in the Gallery's collections were made by Francis Sullivan, who was appointed assist-

ant restorer to the Gallery on December 1, 1949. All work was completed in the restorer's studio in the Gallery with the exception of the restoration of two paintings begun before the death of Mr. Pichetto in January 1949 and completed in the New York studio by Mr. Pichetto's residual staff. Both paintings have been returned to the Gallery in good condition.

PUBLICATIONS

During the year Huntington Cairns contributed articles and reviews to the Yale Law Journal, the Harvard Law Review, the Virginia Quarterly Review, and the Baltimore Evening Sun. He also delivered four lectures at the Johns Hopkins University on the theory of criticism.

The series of 12 articles on "Masterpieces in the Gallery" by John Walker, published in the Ladies' Home Journal, was completed in December 1949, making a total of 36 articles by Mr. Walker, principally on the Gallery's collection, published in that periodical since 1946. An article by Mr. Walker on "The Vienna Treasures and Their Collectors" appeared in the National Geographic Magazine for June 1950. Erwin O. Christensen contributed two articles to Antiques Magazine: "Justice," published in January 1950, and "What Is American Folk Art?" published in May 1950. James W. Lane contributed four book reviews to the Catholic World, on "John Singleton Copley," by James T. Flexner, "Cream Hill," by Lewis Gannett, "The Twelve Seasons," by Joseph Wood Krutch, and "The Virgin and Child," with introduction by Thomas Bodkin; he also wrote a review of "Martin Johnson Heade," by Robert G. McIntyre, for the summer, 1949, issue of the College Art Journal. An article by Charles M. Richards, "Standard Procedure for Intermuseum Loans," was published in Museum News.

An illustrated catalog of recent acquisitions to the Rosenwald Collection was compiled by Miss Elizabeth Mongan and was issued for the opening of the Rosenwald exhibition on April 9, 1950. An illustrated catalog of the "Makers of History in Washington, 1800-1950," was prepared by Perry B. Cott and James W. Lane for the opening of the "Makers of History in Washington, 1800-1950" exhibition.

A second volume of "Masterpieces of Painting from the National Gallery of Art," by Huntington Cairns and John Walker, is in process, and Perry B. Cott has begun the preparation of a catalog on Renaissance bronzes.

During the past fiscal year the publications fund supplemented the group of color reproductions offered to the public with four new color postcard subjects and a new 11-by-14-inch reproduction; 12 more of the latter are on order, to be utilized in a forthcoming

portfolio of religious subjects. Four large collotype reproductions were added to the long list of this type of print available.

A companion volume to "Masterpieces of Painting," namely, "Masterpieces of Sculpture from the National Gallery of Art," an illustrated catalog of the Mellon Collection, and "Popular Art in the United States," by Erwin O. Christensen, were placed on sale during the fiscal year 1951. The third large printing of the illustrated Kress catalog was completed during the year.

The publication date of "The Index of American Design" (formerly entitled "Made in America"), by Erwin O. Christensen, has been set at October 15, 1950, and "Pictures from America," by John Walker, is also to be published soon.

While the exhibition of Art Treasures from the Vienna Collections was on view, the Publications Fund distributed over 53,000 catalogs and more than 36,000 color postcards; and made available other publications dealing with the Austrian exhibition.

EDUCATIONAL PROGRAM

More than 28,000 persons attended the General, Congressional, and Special Tours during the fiscal year, with the attendance for the "Picture of the Week" talks reaching a total of over 26,000. Lectures on special subjects, with lantern slides, were given in the auditorium on Sunday afternoons; 13 of these were by visiting lecturers, and the total attendance was 17,000. A black-and-white strip-film of 300 representative paintings from the Gallery's collections has been very much in demand. The slide collection and the film "The National Gallery of Art" have been widely distributed during the year.

The Educational Office has continued the publication of a monthly Calendar of Events announcing all the Gallery activities, including notices of exhibitions, new publications, lectures, gallery talks, tours, and concerts. Approximately 4,600 copies of the calendar are mailed each month.

LIBRARY

A very important contribution to the Library this year was the purchase of 997 books, 3,395 pamphlets, 15,518 photographs, 418 periodicals, and 9 subscriptions from funds presented to the Gallery by Paul Mellon. Other gifts included 153 books, 103 of them presented by Lessing J. Rosenwald, 42 pamphlets, and 1 periodical. Fifteen books and subscriptions to 30 periodicals were purchased from other funds. Five hundred and ninety books, pamphlets, periodicals, and bulletins were received on exchange from other institutions. During the year 535 persons other than the Gallery staff used the Library for purposes of art research either in person or by phone.

INDEX OF AMERICAN DESIGN

During the fiscal year, 108 examples from the Index were reproduced in publications, and 719 examples were borrowed for use in forthcoming publications. More than 1,100 photographs of the Index were sent out for use by designers, for research and study, and for publicity. The Index material was studied by 468 persons, 399 of whom were new users. Three hundred and thirty-nine slides were circulated for use in lectures. A total of 2,057 Index plates were sent out for exhibition and publication purposes during the fiscal year 1950.

CONSTRUCTION OF NEW GALLERIES AND OFFICES

In keeping with the recommendation of the Committee on the Building and the Board of Trustees, a contract was entered into on June 19, 1949, for the completion of 12 galleries in the east end of the building. Eight of these galleries were completed in time to be used for the Sesquicentennial exhibition, "Makers of History in Washington, 1800-1950." The remaining four were completed by July 15, 1950. A similar contract was entered into on March 10, 1950, for the completion of five offices and a slide storage room in the west wing on the ground floor. Work is progressing satisfactorily, and it is contemplated that this project will be completed by early fall.

CARE AND MAINTENANCE OF THE BUILDING

The Gallery building and grounds, and the mechanical equipment, were maintained throughout the year at the high standard established in the past. Among the nonrecurring and unusual items were the construction of a 48-foot cold frame to increase facilities for growing plants for the garden courts; the construction of bases and pedestals for exhibition material of the Austrian exhibition; construction of additional exhibition facilities for the Bliss exhibit; complete overhauling and realigning of air-conditioning refrigeration machine No. 3; and the construction of storage facilities on the 81-foot level.

COMMITTEE OF EXPERT EXAMINERS

The United States Civil Service Commission's Committee of Expert Examiners, composed of staff members of the Gallery, graded the Museum Art Specialist examination papers. Registers of eligibles were established, and appointments made therefrom.

OTHER ACTIVITIES

Forty-five Sunday evening concerts were given in the East Garden Court during the fiscal year. Two Saturday afternoon concerts were given in the lecture hall, thus making a total of 47 musical performances at the Gallery this year. The Seventh Annual Music Festival

was held in May, with 41 works by American composers included in the programs.

The Photographic Laboratory of the Gallery produced 11,000 prints, 1,029 black-and-white slides, 903 color slides, and 2,418 negatives in the fiscal year 1950, in addition to infrared and ultra-violet photographs, X-rays, and color separations.

A total of 2,890 press releases, 171 permits to copy paintings in the Gallery, and 182 special permits to photograph in the Gallery were issued during the fiscal year 1950.

OTHER GIFTS

Gifts of books on works of art and related material were made to the Gallery by Paul Mellon and others. Gifts of money during the fiscal year 1950 were made by The A. W. Mellon Educational and Charitable Trust, Lessing J. Rosenwald, and Mrs. C. B. Myhre. An additional cash bequest was received from the Estate of the late William Nelson Cromwell.

AUDIT OF PRIVATE FUNDS OF THE GALLERY

An audit of the private funds of the Gallery has been made for the fiscal year ended June 30, 1950, by Price, Waterhouse & Co., public accountants, and the certificate of that company on its examination of the accounting records maintained for such funds will be forwarded to the Gallery.

Respectfully submitted.

HUNTINGTON CAIRNS, *Secretary.*

THE SECRETARY,
Smithsonian Institution.

APPENDIX 3

REPORT ON THE NATIONAL COLLECTION OF FINE ARTS

SIR: I have the honor to submit the following report on the activities of the National Collection of Fine Arts for the fiscal year ended June 30, 1950:

THE SMITHSONIAN ART COMMISSION

The twenty-seventh annual meeting of the Smithsonian Art Commission was held in the Regents' Room of the Smithsonian Building on Tuesday, December 6, 1949. The members present were: Paul Manship, chairman; Alexander Wetmore, secretary (member, ex officio); John Nicholas Brown, Eugene Speicher, George Hewitt Myers, George H. Edgell, Robert Woods Bliss, Archibald G. Wenley, and David E. Finley. Thomas M. Beggs, Director of the National Collection of Fine Arts, was also present.

The Commission recommended the reelection of John Nicholas Brown, George Hewitt Myers, Robert Woods Bliss, and Mahonri M. Young for the usual 4-year period. The following officers were re-elected for the ensuing year: Paul Manship, chairman; Robert Woods Bliss, vice chairman, and Dr. Alexander Wetmore, secretary. The following were elected members of the executive committee for the ensuing year: David E. Finley, chairman, Robert Woods Bliss, Gilmore D. Clarke, and George Hewitt Myers. Paul Manship, as chairman of the Commission, and Dr. Alexander Wetmore, as secretary of the Commission, are ex-officio members of the executive committee.

The secretary reviewed briefly the legal status of the John Gellatly collection, suit for the possession of which had been decided in favor of the Smithsonian Institution in the District of Columbia Court of Appeals. The Director of the National Collection of Fine Arts reported upon progress in the reorganization of sections of the permanent exhibition and outlined further plans for its improvement in appearance and usefulness. A research project on the spectrochemical analysis of ancient glass, inspired by the Archeological Institute of America and to be sponsored by the National Collection of Fine Arts with technical aid from the National Bureau of Standards, was briefly described.

The following works of art were accepted for the National Collection of Fine Arts:

Oil painting, Gold Mining, Cripple Creek, by Ernest Lawson, N. A. Henry Ward Ranger bequest.

Portrait in oil of Chief Justice Salmon P. Chase, by James Reid Lambdin. Offered anonymously.

DEPOSITS

The following deposits for the Collection were made during the year:

Bronze bust of Orville Wright, by Oskar J. W. Hansen, presented by Mr. and Mrs. Robert Frackelton, in memory of Lt. Rollin N. Conwell, Jr., U.S.M.C.R., was accepted by the Smithsonian Institution for the National Air Museum, and deposited January 10, 1950. (Withdrawn by the National Air Museum February 3, 1950.)

Oil, on wood panel, Reclining Tiger, by Charles R. Knight, bequest of Vernon Bailey, was accepted by the Smithsonian Institution for the U. S. National Museum (division of mammals), and deposited January 10, 1950.

Ninety-six drawings and paintings, by Abbott H. Thayer, N. A. (1849-1921), made during his study of protective coloration in the Animal Kingdom, were accepted by the Smithsonian Institution for the United States National Museum (division of birds), as a loan from the heirs of the artist, through David Reasoner, and deposited February 17, 1950.

TRANSFERS

Two oils, Beach of Bass Rocks, Gloucester, Mass., by Frank Knox Morton Rehn, N. A. (1848-1914), and Fog, by James Craig Nicoll, N. A. (1847-1918), bequest of Martha L. Loomis to the United States National Museum in 1935, were transferred from the division of graphic arts on August 26, 1949.

THE CATHERINE WALDEN MYER FUND

One miniature, water color on ivory, was acquired from the fund established through the bequest of the late Catherine Walden Myer, as follows:

70. Robert A. B. S. Sparrow, attributed to Benjamin Trott; from Edmund Bury, Philadelphia, Pa.

LOANS ACCEPTED

Orrefors crystal vase, signed Edvard Hald, was lent by Mr. and Mrs. Hugh Smith on December 1, 1949.

Fifty miniatures from the Pepita Milmore collection were lent by Mrs. Henry L. Milmore on April 24 and 26, 1950.

WITHDRAWALS BY OWNERS

Two miniatures, Roswell Shurtleff and Anna Pope Shurtleff, by Frank Barbour, lent in 1941, were withdrawn on October 13, 1949, by order of the owner, Mrs. O. A. Mechlin.

Three oils, Portraits of Joseph Turner and Elizabeth Oswald Chew, by John Wollaston, lent in 1932, and Portrait of John Eager Howard, attributed to Charles Willson Peale or Robert Edge Pine, lent in 1934, were withdrawn on November 7, 1949, by order of the owner, Mrs. H. H. Norton.

A miniature, Mrs. Robert Means, by Edward G. Malbone, lent in 1939, was withdrawn on December 9, 1949, by the owner, John J. Pringle, Jr.

An oil painting, Landscape, attributed to Richard Wilson, lent in 1931, was withdrawn on June 28, 1950, by the owner, Mrs. Mabel Perkins Ruggles.

LOANS TO OTHER MUSEUMS AND ORGANIZATIONS

Oil, portrait of Andrew Jackson, by Ralph E. W. Earl, was lent to the Department of State September 20, 1949, to be hung in the office of the Under Secretary of State for a period not to exceed 4 years.

Oil, Thomas A. Edison Listening to His First Perfected Phonograph, by Col. Abraham Archibald Anderson, was lent to the Morse Exhibition of Arts and Science, sponsored by the National Academy of Design, for the one hundred and twenty-fifth anniversary of its founding, held at the American Museum of Natural History, January 18 to February 28, 1950. (Returned March 7, 1950.)

Seven portraits by G. P. A. Healy, Gen. W. T. Sherman, Mrs. W. T. Sherman, William G. Preston, F. P. G. Guizot, President John Tyler, Col. A. G. Brackett, and Gen. A. J. Myer, were lent to the Virginia Museum of Fine Arts for an exhibition entitled "Healy's Sitters or a Portrait Panorama of the Victorian Age," from January 24 through March 5, 1950. (Returned March 16, 1950.)

Fifty-two items from the exhibition of Abbott H. Thayer's studies on the protective coloration in the Animal Kingdom were lent, with the consent of the owners, for exhibition in the American Academy of Arts and Sciences from January 12 through February 8, 1950. (Returned February 15, 1950.)

Oil, portrait of John Muir, by Orlando Rouland, was lent to the Bureau of the Budget on February 13, 1950, for a period not to exceed 4 years.

Oil, portrait of Capt. John Ericsson, by Arvid Nyholm, was lent to the House Judiciary Committee on March 3, 1950, for a period not to exceed 4 years.

Oil, portrait of Commodore Stephen Decatur, by Gilbert Stuart, was lent to the Truxtun-Decatur Naval Museum on April 27, 1950, for a period not to exceed 1 year.

Oil, portrait of Samuel P. Langley, by Robert Gordon Hardie, was lent to the Langley Aeronautical Laboratory of the National Advisory Committee for Aeronautics, Langley Field, Va., May 1, 1950, for an indefinite period.

Three oil paintings, Gen. John J. Pershing, by Douglas Volk; Admiral William S. Sims, by Irving R. Wiles; and Gen. William T.

Sherman, by George P. A. Healy; and one marble bust of Alexander Graham Bell, by Moses W. Dykaar, were lent to the National Gallery of Art, to be included in the Sesquicentennial celebration, "Makers of History in Washington, 1800-1950," from June 28 through November 19, 1950.

Oil, December Uplands, by Bruce Crane, was lent to the executive office, Council of Economic Advisers, on June 27, 1950, to be hung in room 372A, Old State Building, for a period not to exceed 4 years.

LOANS RETURNED

Four oil paintings lent to the Public Library of the District of Columbia in April 1940 were returned on November 22, 1949: Portrait of Thomas McKean, by Charles Willson Peale, and Portrait of Mary Abigail Willing Coale, by Thomas Sully, from the Georgetown Branch; Madonna with Halo of Stars, by an unknown artist, from the Southeastern Branch; and Musa Regina, by Henry Oliver Walker, from the Northeastern Branch.

THE HENRY WARD RANGER FUND

Since it is a provision of the Ranger bequest that the paintings purchased by the Council of the National Academy of Design from the fund provided by the Henry Ward Ranger bequest, and assigned to American art institutions, may be claimed by the National Collection of Fine Arts during the 5-year period beginning 10 years after the death of the artist represented, two paintings were recalled for action of the Smithsonian Art Commission at its meeting December 6, 1950:

Oil painting, Gold Mining, Cripple Creek, by Ernest Lawson, listed earlier in this report, was accepted by the Commission to become a permanent accession.

Frances, by Frederick Carl Frieseke, N. A., was returned to the Washington County Museum of Fine Arts, Hagerstown, Md., where it was originally assigned in 1932.

THE NATIONAL COLLECTION OF FINE ARTS REFERENCE LIBRARY

Three hundred and eighty-four publications (260 volumes and 124 pamphlets) were accessioned during the year, bringing the total in the National Collection of Fine Arts Library to 11,746.

INFORMATION SERVICE

The requests of 1,255 visitors for information received special attention, as did many similar requests by mail and phone; 706 art works were submitted for identification.

The Director and Paul V. Gardner, curator of ceramics, gave lectures on art topics during the year to a number of groups, including the art section of the University Women's Club; the Arts Club and officers of art societies in the Metropolitan area; the Kiln Club; the District of Columbia Chapter of the Daughters of the American Revolution; the Alexandria Association at Gadsby's Tavern; and the American Federation of Jewish Women. They also served as judges or as members of juries of selection and award for a number of exhibitions held in Washington.

SPECIAL EXHIBITIONS

Thirteen special exhibitions were held during the year, as follows:

July 1 through 31, 1949.—An exhibition of 60 water colors and sketches of Greenland, painted between 1899 and 1911 by Christine Deichmann (1869–1945), was shown on screens in the lobby. A list was mimeographed.

August 12 through December 31, 1949.—Centennial Exhibition of Paintings by Abbott Handerson Thayer, N. A. (1849–1921), in the Gellatly Collection and the Freer Gallery of Art, with the cooperation of the latter. Supplementary exhibits in the lobby consisted of (1) Thayer's studies on the protective coloration in the Animal Kingdom, (2) camouflage, and (3) works by his former students, consisting of 155 oils, water colors, pastels, models, and photographs. A catalog was printed.

September 8 through 28, 1949.—Exhibition of 262 oils, water colors, and prints, by Madame Henriette Reuchlin, held under the patronage of His Excellency, E. N. Van Kleffens, Ambassador of the Netherlands to the United States. A list was mimeographed.

November 6 through 29, 1949.—The Twelfth Metropolitan State Art Contest, held under the auspices of the District of Columbia Chapter, American Artists Professional League assisted by the Entre Nous Club, consisting of 324 paintings, sculpture, prints, ceramics, and metalcraft. A catalog was privately printed.

December 10 through 30, 1949.—The Fifty-eighth Annual Exhibition of the Society of Washington Artists, consisting of 71 paintings and 11 pieces of sculpture. A catalog was privately printed.

January 16 through 29, 1950.—Eighty-two drawings in pencil, pen, charcoal, chalk, crayon, and water color, by contemporary French artists, from the permanent collection.

February 4 through 27, 1950.—Exhibition of 335 drawings and paintings of Indo-China, by Jean Despujols. A catalog was provided.

March 4 through 26, 1950.—A selection of 34 oil paintings and 1 bronze bust, from the William T. Evans collection.

March 30 through April 2, 1950.—A gros point carpet (10' 2" by 6' 9½"), made by Queen Mary, and the specially constructed oak casket in which it came. A catalog was provided by the British Information Service.

April 2 through 27, 1950.—Biennial Exhibition of the National League of American Pen Women, consisting of 356 paintings, sculpture, prints, ceramics, and metalcraft. A catalog was privately printed.

April 6 through May 8, 1950.—Exhibition of 50 miniature paintings commemorating the Fiftieth Anniversary of the American Society of Miniature Painters.

June 4 through 30, 1950.—The Seventeenth Annual Exhibition of the Miniature Painters, Sculptors, and Gravers Society of Washington, D. C., consisting of 203 examples.

June 8 through 30, 1950.—Exhibition of 56 paintings of Ancient Egyptian Monuments, by Joseph Lindon Smith, held under the patronage of His Excellency Mohamed Kamil Abdul Rahim Bey, Ambassador of Egypt. A catalog was provided.

Respectfully submitted.

THOMAS M. BEGGS, *Director.*

Dr. A. WETMORE,

Secretary, Smithsonian Institution.

APPENDIX 4

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the thirtieth annual report on the Freer Gallery of Art for the year ended June 30, 1950.

THE COLLECTIONS

Additions to the collections by purchase were as follows:

BRASS

- 49.11. Egyptian (middle of 13th century). Brass bowl with gold and silver inlay. In center band six cartouches with *thuth* writing alternating with roundels with horsemen. Bottom and inside engraved. 0.072 x 0.166.

BRONZE

- 49.10. Chinese, Chou dynasty (1122-256 B. C., early). A covered ceremonial vessel of the type *kuang*. Design cast in low and high relief representing mainly feline and bird forms. Smooth gray-green patina. Eight-character inscription inside cover and bottom. (Illustrated.) 0.229 x 0.246 x 0.107.
- 49.15. Chinese, Chou dynasty (1122-256 B. C., early). A monster mask. Casting in hollow relief with linear intaglio decoration. Blue-gray patina with incrustations of malachite and azurite. 0.174 x 0.234.
- 49.17. Chinese, T'ang dynasty (A. D. 618-906). Square mirror with lacquered reverse surface decorated with birds, phoenixes, butterflies, plants, etc., in gold and silver, inlaid into the lacquer. Incrustations of earth and malachite. 0.141 x 0.145.
- 49.24. Chinese, Chou dynasty (1122-256 B. C., late). Garment hook (*kou*). Gilded with all-over incised pattern. Areas of green patination. Length: 0.103.
- 49.25. Chinese, Chou dynasty (1122-256 B. C., late). Garment hook (*kou*). Mounted with gold designs placed like cloisons and inlaid with turquoise. Areas of green patination. Length: 0.197.

CRYSTAL

- 49.14. Egyptian, *Ikhshidid* or early *Fātimid* period (middle of 10th century). Flat, oval-shaped vessel with two low excrescences on the narrow sides. Arabesque decorations forming a stylized tree on the front and back are executed in low, sharp-edged relief. Austrian enameled gold mount of about 1600. 0.152 x 0.068 x 0.035.

JADE

- 49.16. Chinese, Chou dynasty (1122-256 B. C., late). Flat carving of dragon, carved on both sides. 0.046 x 0.075.

LACQUER

- 49.22. Chinese, Chou dynasty (1122-256 B. C., late). Ewer of brownish lacquer over wood, representing a crouching animal. Decorations carved in relief. Handle detached; occasional cracks through wood and lacquer. 0.156 x 0.307 x 0.153.

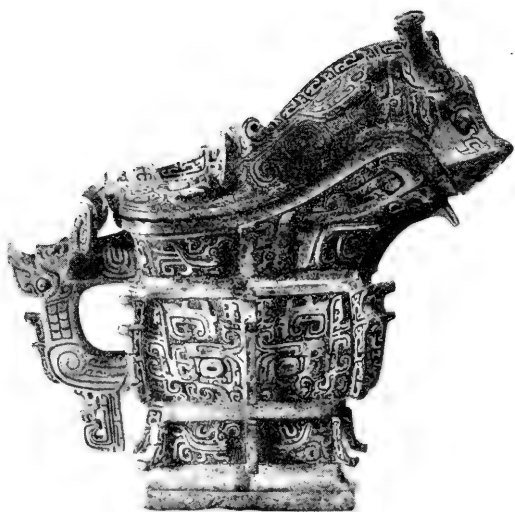


50.1

RECENT ADDITION TO THE COLLECTION OF THE FREER GALLERY OF ART



49.27



49.10

RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART

MANUSCRIPT

- 50.3. Armenian, 12th-13th century. A volume in a tooled-leather binding with a *fourchée*-like cross tooled on the front cover: The *Gospel* according to the four Evangelists. Two hundred and seventy parchment leaves written in angular *erkat'agir* (uncial). Initials, paragraphs, titles, arcades, and six miniatures in color and gold. 0.332 x 0.246.

PAINTING

- 49.18. Indian, Mughal, school of Akbar (third quarter of the 16th century). "The Taking of Prisoners at the Prince's Court," from the *Hamza-nāma*, executed for the Emperors Humāyūn and Akbar. Painted in gold and color on cotton cloth. 0.671 x 0.512.
- 50.1. Persian (first half of the 16th century). Solomon (?) and his Flying Throne, Borne by Angels. Drawing on paper, tinted with gold and color. (Illustrated.) 0.308 x 0.198.
- 50.2. Persian (first half of the 16th century). The Garden of the Fairies. Drawing on paper, slightly tinted with color and gold. 0.279 x 0.172.

POTTERY

- 49.12. Chinese, Sung dynasty (A. D. 960-1280).
Chün ware. Vase with pear-shaped body and tall, slender, slightly flaring neck, flaring foot; reddish-buff stoneware, fired hard; thick opaque glaze, shades of bluish gray with dark flecks; scattered greenish-gray patches with red flecks. Glaze ends unevenly at foot. 0.344 x 0.143.
- 49.13. Chinese, T'ang dynasty (A. D. 618-906).
Three-color ware. Dish with low, sloping sides and everted rim, three spreading feet; fine-grained soft white clay; soft lead glaze in green, white, and yellowish brown; considerable iridescence and flaking; bottom unglazed; decorated with floral patterns deeply impressed in clay. 0.060 x 0.290.
- 49.23. Chinese, Sung dynasty (A. D. 960-1280).
Ting yao. Dish with six-lobed rim bound in brass; thin, sharply cut foot. Wooden stand. Fine-grained porcelain fired hard; high-fired glossy, transparent, ivory-colored glaze; "tear drops" on outside; covers footrim; decoration of ducks, waves, and water plants painted in slip under glaze inside. 0.040 x 0.188.
- 49.26. Chinese, T'ang dynasty (A. D. 618-906).
Mortuary figurine of water buffalo and rider. Made of soft white clay covered with transparent glaze in blue, white, brown, and green; finely crazed. Horns and ears slightly chipped. 0.158 x 0.163 x 0.102.
- 49.27. Chinese, T'ang dynasty (A. D. 618-906).
Mortuary figurine of a female dancer. Made of hard, close-grained clay in buff white with minute black specks; transparent glaze in green and brown, finely crazed; head unglazed with traces of pigment on lips and eyes. (Illustrated.) 0.282 x 0.103.
- 50.4. Chinese, Chin dynasty (A. D. 265-420).
Tripodal vessel of the type *lien*, with cover; hard gray pottery with decorations incised and in relief; the three feet in the form of crouching bears; inscription of seven characters written in cinnabar around body of vessel. 0.280 x 0.332.

- 49.19. Persian, Kāshān (*circa* A. D. 1200). Double-shell ewer with rooster-head neck and tail-shaped handle. Ajouré work with black design and cobalt spots under turquoise glaze. Slight iridescence in spots. 0.291 x 0.181.

SCULPTURE

- 49.9. Indian, Gandhara (*circa* A. D. 2d century). Frieze showing four scenes from the life of the Buddha: Birth, Enlightenment, First Preaching, Nirvana. Carved in high relief on seven pieces of dark gray-blue slate. 0.670 x 2.898 x 0.098.
- 49.20. Japanese, Kamakura period (A. D. 1185-1333). Guardian figure in an attitude of violent tension: skirt swinging to proper left, remains of jeweled pendant on bare torso; cleaned and repaired; inscription on tennon below left foot. Wood. Pair with 49.21. Height: 2.264.
- 49.21. Japanese, Kamakura period (A. D. 1185-1333). Guardian figure in an attitude of violent tension: skirt swinging to proper right, remains of jeweled pendant on bare torso; cleaned and repaired. Wood. Pair with 49.20. Height: 2.335.

WOOD CARVING

- 49.7 Persian, Seljuq (A. D. 1148 [543 H.]). A pair of doors. Arabesques and A-B. inscription in *kūfic* and decorative *nashkhī* in various compartments; on back, frames with incised geometric designs and undecorated boards. A: 2.278 x 0.625; B: 2.280 x 0.610.
- 49.8 Persian, Mongol period (A. D. 1285 [684 H.]). A pair of doors. Ara- A-B. besque designs on one side, geometrical strapwork with decorated polygonal inserts and framing *nashkhī* inscriptions on the other. Many of the polygonal inserts lost and substituted by plain modern ones. A: 2.147 x 0.555; B: 2.172 x 0.550.

The work of the staff members has been devoted to the study of new accessions and objects submitted for purchase and to general research within the collections of Chinese, Japanese, Persian, Arabic, and Indian materials. Reports, oral or written, were made upon 2,236 objects, as follows: From individuals, 1,075; from dealers, 837; at other museums, 324. There were 505 photographs of objects submitted for examination, and 295 Oriental-language inscriptions were translated. Docent service and other lectures given by staff members are listed below.

REPAIRS TO THE COLLECTIONS

A total of 20 objects were cleaned, resurfaced, remounted, or repaired as follows:

American paintings cleaned and resurfaced.....	6
Chinese paintings remounted.....	2
Chinese paintings repaired.....	1
Japanese paintings remounted.....	5
Japanese paintings repaired.....	1
Arabic manuscript pages repaired.....	1
Persian manuscript pages repaired.....	2
Japanese sculptures repaired.....	2

The repair and restoration of the ceiling of the Whistler Peacock Room, mentioned in last year's report, has been completed. The final work of cleaning and restoring the wainscoting, shutters, and doors, now in progress, is being carried on as before by John and Richard Finlayson, of the Museum of Fine Arts, Boston.

CHANGES IN EXHIBITIONS

Changes in exhibitions totaled 149, as follows:

American paintings.....	82
Chinese bronzes.....	10
Chinese gold.....	2
Chinese silver gilt.....	2
Indian paintings.....	29
Indian stone sculpture.....	4
Japanese lacquer.....	12
Japanese paintings.....	4
Japanese wood sculpture.....	2
Persian wood carving.....	2

LIBRARY

During the year the following work was accomplished in the library: Accessions, including books, pamphlets, periodicals, rubbings, study material, and photographs, 826; cataloging of all kinds, including cards typed and filed, 5,518; binding, repairing, and mounting, 762. The Japanese publication *Bijutsu Kenkyu* was analyzed, and work on the analyzing of the Japanese periodical *Kokka* was started.

PUBLICATIONS

Two publications of the Gallery were issued during the year:

Guest, Grace Dunham: Shiraz Painting in the Sixteenth Century (Oriental Studies No. 4). S. I. Publ. 3978. October 1949.

Stubbs, Burns A.: James McNeill Whistler, A Biographical Outline Illustrated from the Collections of the Freer Gallery of Art (Occasional Papers, vol. 1, No. 4). S. I. Publ. 3994. February 1950.

One article by a staff member appeared in an outside publication:

Wenley, A. G.: The Question of the Po-Shan-Hsiang-Lu. Archives of the Chinese Art Society of America, vol. 3, p. 5, 1948-1949.

REPRODUCTIONS

During the year the photographic laboratory made 3,631 prints, 434 glass negatives, and 19 lantern slides.

BUILDING

The cabinet shop has been constantly occupied in the usual work of making necessary equipment, certain repairs to the collections, the

Peacock Room, and minor repairs to the building. Lack of a painter, however, has badly handicapped operations, so that work of this nature is far behind schedule. At least half of the exhibition galleries need redecorating, while many other parts of the building are in crying need of attention.

An important project was the construction of a counter for the display and sale of publications and photographs in the entrance lobby. This relieved the understaffed administration office of considerable work.

ATTENDANCE

The Gallery was open to the public from 9 to 4:30 every day except Christmas Day. The total number of visitors to come in the main entrance was 62,801. The highest monthly attendance was in August with 8,550, and the lowest was in December with 1,951.

There were 1,626 visitors to the main office during the year.

COLLABORATION WITH THE UNIVERSITY OF MICHIGAN

Under the provisions of the will of the late Charles L. Freer, there was created at the University of Michigan a fund, the income from which is to be used to add to the knowledge and appreciation of Oriental art, primarily in aid of research to be conducted by experts regarding the art objects embraced in a collection of Oriental art transferred by the testator to the Smithsonian Institution, and for the publication of the results of such research. Therefore, the University of Michigan and the Freer Gallery of Art have entered into a collaborative arrangement to carry out the broad general principles concerning the program in Oriental art contemplated by the will of Charles L. Freer. Briefly, to implement this arrangement the following actions have been or will be taken:

1. Mr. Wenley has been appointed research professor of Oriental art in the Department of Fine Arts of the University of Michigan without salary and on an annual basis.
2. Dr. Ettinghausen has been appointed research professor of Islamic art in the Department of Fine Arts of the University of Michigan without salary and on an annual basis.
3. The university shall appoint a professor of Oriental art in the Department of Fine Arts of the University of Michigan as soon as practicable. It is the purpose of the university to appoint to this position a scholar to whom the Gallery will also be prepared to offer a joint appointment, without salary and on an annual basis, as research associate in the Gallery.
4. The university has appointed a committee of the Freer fund consisting of the dean of the Horace H. Rackham School of Graduate Studies, the chairman of the Department of Fine Arts, the chairman of the General Committee of the Division of Fine Arts, and the research professor of Oriental art in the Department of Fine Arts (Director of the Freer Gallery). This committee is authorized to determine the program of research

and publication to be carried on with funds derived from the income of the Freer fund, and to prepare an annual budget for presentation to the provost of the university for the expenditure of such funds.

5. The University of Michigan and the Freer Gallery of Art are collaborating in the publication of a series to be known as *Ars Orientalis*. This will succeed the university's Freer fund publication *Ars Islamica*, which has been edited at the Freer Gallery since 1944. In its greater breadth of treatment *Ars Orientalis* will supplement other Gallery publications.
6. The Freer Fund Committee has established a Charles L. Freer fellowship in Oriental art, which may be given to candidates for the doctoral degree and entitles the holder to a year of advanced work at the Freer Gallery of Art. In this connection the Director of the Freer Gallery is serving on the standing committee on graduate work in Oriental art of the Department of Fine Arts, University of Michigan.

Either party to the above-mentioned arrangement may terminate this by the giving of a year's notice to the other party of its intention to terminate.

DOCENT SERVICE AND OTHER STAFF ACTIVITIES

By request 19 groups met in the exhibition galleries for instruction by staff members. Total attendance was 369.

On invitation the following lectures were given outside the Gallery by staff members:

1950

- Jan. 9. Mr. Pope lectured at the University Women's Club on "Beginnings of Glaze and Porcelain and Their Development through the Ming Dynasty." (Illustrated.) Attendance, 90.
- Feb. 2. Mr. Pope lectured at the Chevy Chase Women's Club on "Chinese Paintings." (Illustrated.) Attendance, 60.
- Mar. 10. Mr. Pope lectured at the Cleveland Museum, Cleveland, Ohio, on "Introduction of Chinese Porcelain to Europe." (Illustrated.) Attendance, 150.

HONORARY DUTIES

During the year, members of the staff undertook honorary duties outside the Institution as follows:

Mr. Wenley appointed a member of the Nominating Committee of the Far Eastern Association.

Mr. Pope appointed art editor of the *Far Eastern Quarterly*.

Respectfully submitted.

A. G. WENLEY, *Director*.

Dr. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1950, conducted in accordance with the Act of Congress of April 10, 1928, as amended August 22, 1949, which provides for continuing "independently or in cooperation anthropological researches among the American Indians and the natives of lands under the jurisdiction or protection of the United States and the excavation and preservation of archeologic remains."

SYSTEMATIC RESEARCHES

Dr. M. W. Stirling, Director of the Bureau, devoted most of his time during the fiscal year to administrative affairs of the Bureau. He also continued studies on the archeological collections made in Panamá during the winter of 1948-49, particularly on the ceramic collection from the site of Utivé in the Province of Panamá. With the exception of a few brief trips for the purpose of attending scientific meetings or giving lectures, the entire year was spent in Washington.

Dr. Frank H. H. Roberts, Jr., Associate Director of the Bureau and Director of the River Basin Surveys, spent most of the fiscal year in administering and directing the River Basin Surveys. In September he attended the Twenty-ninth International Congress of Americanists where he gave an illustrated talk on the program and work of the River Basin Surveys. Early in October he participated in the annual meeting of the National Council for Historic Sites and Buildings at Williamsburg, Va. From Williamsburg he went to the Joshua S. and John E. Williamson farm near Dinwiddie to examine an archeological site where considerable material attributable to the eastern variant of the Folsom culture had been found. That particular site is one of the most extensive of its kind thus far noted in the East, and, if excavated, should provide valuable information.

Later in October Dr. Roberts visited the Missouri Basin headquarters at Lincoln, Nebr., and, accompanied by Paul L. Cooper, proceeded to the Angostura Reservoir in South Dakota where a series of excavations was under way. After spending several days with the field party, they went to Wyoming to examine the site for

the proposed Edgemont Reservoir on the Cheyenne River. From there they went to Fort Collins, Colo., where the Horsetooth Reservoir is under construction, and examined paleontological and archeological specimens uncovered in the process of the work. Returning to Washington early in November, Dr. Roberts went to Richmond, Va., and gave the principal address before the annual meeting of the Eastern States Archeological Federation. The subject of his talk was the progress and results of the River Basin program.

Late in November and early in December Dr. Roberts was again in Lincoln, Nebr., where he assisted in making plans for reorganizing the laboratory and field headquarters. While there he took part in the Seventh Conference for Plains Archeology and presided over one of the symposia dealing with the problems of Plains archeology.

In February and March Dr. Roberts visited the Departments of Anthropology at the University of Utah, Salt Lake City; the University of Washington, Seattle; the University of Oregon, Eugene; and the University of California, Berkeley. He discussed the plans for field work during the coming season and made arrangements for student help and field assistants for the River Basin Surveys parties. While at Eugene he also inspected the field headquarters and laboratory for the Columbia Basin project and assisted Joel L. Shiner, the acting field director, in making plans for the summer season. En route back to Washington, Dr. Roberts visited the Department of Anthropology at the University of Denver, where he talked with Arnold M. Withers about the cooperation of that institution in the program in Colorado. From there he proceeded to Lincoln to plan for the summer's work in that area. At that time he also spoke on the River Basin program before the annual meeting of the Nebraska State Press Association at Omaha.

In May Dr. Roberts visited the Fort Gibson Reservoir in Oklahoma and discussed plans for additional projects with the District Engineer at Tulsa. At Norman, Okla., he examined materials which had been salvaged from sites at the Fort Gibson Reservoir by a field party from the University of Oklahoma and also attended sessions of the annual meeting of the Society for American Archaeology. From Oklahoma Dr. Roberts went to Texas, visiting the Garza-Little Elm, Lavon, and Belton Reservoir projects. He also spent several days at the Whitney Reservoir where one of the River Basin Surveys parties under Robert L. Stephenson was excavating a series of Indian sites. From the Whitney Reservoir he went to Austin to inspect the field headquarters and laboratory located at the University of Texas.

During the period July 1 through October 24, 1949, Dr. John P. Harrington continued the study of the grammar of the Abnaki language at Old Town, Maine. The Abnaki language is the only one of

the Indian languages of New England that is still spoken. Abnaki forms throw considerable light on the closely related, extinct Massachusetts language in which the famous Eliot Indian Bible is written. The earliest vocabulary, or vocabularies, of the Abnaki language resulted from the work of French missionaries in the Kennebec Valley, but the work has been lost. The maps and writings of Capt. John Smith, Champlain, and Lescarbot carry a number of Abnaki place names. The earliest extensive Abnaki vocabulary is that attributed to Capt. George Weymouth and was probably taken down by him in 1605 from Abnaki Indians whom he captured near the St. George Islands, off the eastern end of Penobscot Bay, and took to England. This vocabulary was first printed in 1625. In 1691, 86 years after the Weymouth Abnaki vocabulary had been made, a young French missionary priest named Sebastian Rasles arrived in Canada and compiled his vast French-Abnaki dictionary. This dictionary was captured by the English at the battle of Norridgewock in 1724 and was first printed in 1833.

On February 9, 1950, Dr. Harrington proceeded to Mérida, Yucatán, for the purpose of studying the Maya language. A tape recorder was taken along and 10 half-hour recordings of stories told in the Maya language were obtained. Dr. Harrington returned to Washington on April 11, bringing with him a large quantity of linguistic material.

At the invitation of the Canadian Government, Dr. Henry B. Collins, Jr., conducted archeological investigations on Cornwallis Island in the northern part of the Canadian Arctic Archipelago. Excavations were made at four prehistoric Eskimo village sites at Resolute Bay on the south side of the Island. Dr. Collins and his assistant, Jean P. Mischea, reached Resolute by plane on May 27 after brief stops at Frobisher Bay on Baffin Island, and at Thule in north-west Greenland. The work continued until August 23, 1949. The numerous house ruins on Cornwallis and neighboring islands show that this now uninhabited region once supported a sizable Eskimo population. The Cornwallis Island structures—built of stones, whalebones, and turf—proved to have been made by the Thule Eskimos, a prehistoric group that originated in Alaska and later spread eastward to Canada and Greenland. A large collection of artifacts was obtained which, after study, will be divided between the Smithsonian and the National Museum of Canada, joint sponsors of the work. As the natural history of Cornwallis Island is so little known, an attempt was made to collect representative samples of fossils, minerals, vascular plants, mosses and lichens, insects, and fresh-water invertebrates.

Dr. Collins organized a symposium on Arctic anthropology as part of the program for the Twenty-ninth International Congress of Americanists held in New York in September 1949, the participants being anthropologists, archeologists, and linguists from the United States, Canada, and Denmark who have specialized in Eskimo research.

Dr. Collins continued to serve as chairman of the directing committee of the Bibliography of Arctic Literature and the Roster of Arctic Specialists, two projects that the Arctic Institute of North America is carrying out under contract with the Office of Naval Research for the Departments of the Army, Navy, and Air Force, and the Defense Research Board of Canada. He also participated in organizing the forthcoming Alaska Science Conference to be held under the auspices of the National Research Council in November 1950, serving as a member of the steering committee and chairman of the social sciences division.

During August Dr. William N. Fenton spent 2 weeks studying the archives of the Ontario County Historical Society at Canandaigua, N. Y. In August and September he made tape recordings in the field at Tonawanda and Allegany Seneca reservations. In October he completed a survey of Iroquois materials in the Massachusetts Archives at the State House, in Boston, and found additional Pickering letters in Salem. In December, 34 volumes of the printed journals of the Continental Congress (1774-89) were surveyed and extracted for Iroquois material. During March-May Dr. Fenton was detailed to assist the Department of Justice in the preparation of a case for the Court of Claims concerning Indian lands. In June he was detailed to the Office of Indian Affairs on problems of tribal organization among the Pueblos, the Klamath Indians of California, and the Blackfeet of Montana. Dr. Fenton was in the field on this assignment at the close of the fiscal year.

In September Dr. Gordon R. Willey, anthropologist of the Bureau of American Ethnology, assumed the temporary duties of Acting Director of the Institute of Social Anthropology for the remainder of the fiscal year. However, research under Bureau auspices continued, and preparation of various manuscripts was carried forward. He continued the preparation of the manuscript "Prehistoric Settlement Patterns in the Virú Valley of Northern Peru." Subsequently he began studies on collections from the Canaveral and Ormond Beach Mounds in east Florida, completing these studies in May. The month of June was then devoted to rewriting and revising a manuscript, "Early Ancon and Early Supé: Chavin Horizon Sites of the Central Coast of Perú." This report, approximating 125,000 words,

was written in collaboration with Dr. John M. Corbett and will be released by the Department of Anthropology, Columbia University.

RIVER BASIN SURVEYS

(Report prepared by FRANK H. H. ROBERTS, Jr.)

The River Basin Surveys were organized as a unit of the Bureau of American Ethnology in the fall of 1945. Their purpose was to carry into effect a memorandum of understanding between the National Park Service and the Smithsonian Institution, which provides for the salvage of archeological and paleontological remains occurring in areas to be flooded or otherwise disturbed by the program of the Federal Government for flood-control, irrigation, hydroelectric, and navigation projects. The first actual field work was started in July 1946 and has continued since that date. Throughout the period of operations, the investigations have been conducted in cooperation with the National Park Service and the Bureau of Reclamation of the Department of the Interior, the Corps of Engineers, Department of the Army, and a number of nongovernmental institutions scattered throughout various States. During the past fiscal year the work was financed by a transfer of \$215,886 to the Smithsonian Institution by the National Park Service, derived in part from the National Park Service and in part from the Bureau of Reclamation. The money from the National Park Service was for use in areas outside of the Missouri Basin, while that from the Bureau of Reclamation was for work in the latter area. Because of the fact that the appropriations for fiscal 1950 were made available so late in the summer, the necessary funds could not be transferred to the Smithsonian Institution until the period for field work had passed in many areas. Consequently, less was accomplished than in previous years.

Activities during the year included reconnaissance or surveys for the purpose of locating archeological sites or paleontological deposits that will be involved in construction work or are in locations that eventually will be flooded, and in the excavation of sites located by previous surveys. The survey work covered 26 reservoirs located in 8 States and scattered over 5 river basins. Excavations were completed or under way at the end of the fiscal year in 13 reservoir areas in 9 States. Three of the excavation projects were in areas where digging had been done in previous years, while the remainder were new undertakings. At the close of the fiscal year, the total of the reservoir areas, where surveys had been made or excavations carried on since the beginning of the program in July 1946, was 180 located in 23 States. Archeological sites located and recorded have reached a total of 2,260, of which 484 have been recommended for excavation or additional testing. During

the year preliminary appraisal reports were completed for all the reservoirs surveyed, and 23 reports were mimeographed for limited distribution to the cooperating agencies. This makes a total of 120 such reports issued since the start of the program. The excavations made during fiscal 1950 bring the total for areas where such work has been done to 21. Technical reports on the results of some of that work have appeared in scientific journals, while the completed manuscripts on others are now awaiting publication. Paleontological surveys have been made in 100 reservoirs, 56 being those where archeological work has also been done. The remaining 44 will eventually be visited by archeological parties. Including the reservoir areas where archeological work remains to be done, the over-all total of reservoirs visited is 224.

The distribution by States of all the reservoirs investigated for archeological remains as of June 30, 1950, is as follows: California, 20; Colorado, 23; Georgia, 3; Idaho, 10; Illinois, 2; Iowa, 3; Kansas, 6; Louisiana, 1; Minnesota, 1; Montana, 5; Nebraska, 16; New Mexico, 1; North Dakota, 13; Ohio, 2; Oklahoma, 5; Oregon, 24; South Dakota, 9; Tennessee, 1; Texas, 13; Virginia, 1; Washington, 9; West Virginia, 2; Wyoming, 11. Excavations have thus far been made in: California, 1; Colorado, 1; Georgia, 1; Kansas, 1; Montana, 1; Nebraska, 1; New Mexico, 1; North Dakota, 2; Oklahoma, 1; Oregon, 1; South Dakota, 2; Texas, 3; Virginia, 1; Washington, 3; and Wyoming, 1.

Throughout the fiscal year the River Basin Surveys received full cooperation from the National Park Service, the Bureau of Reclamation, and the Corps of Engineers, as well as various State agencies. At some of the projects guides and transportation were furnished to staff men in the field. At others, office and laboratory space was provided, and in a number of cases labor and mechanical equipment were made available by the construction agency. The assistance provided made possible a greater accomplishment than would otherwise have been possible had it been necessary for the River Basin Surveys men to rely on their own resources. The National Park Service was primarily responsible for procuring the funds necessary for carrying on the program and also served as the liaison between the Smithsonian Institution and the other governmental agencies, not only in Washington but through its several regional offices as well.

General supervision and direction of the work in California, Texas, Louisiana, Georgia, Ohio, and Virginia were from the main office in Washington. The Missouri Basin program was carried on under the direction of a field headquarters and laboratory at Lincoln, Nebr., and the activities in the Columbia Basin were supervised by a field office located at Eugene, Oreg.

Washington office.—The main headquarters of the River Basin Surveys continued under the direction of Dr. Frank H. H. Roberts, Jr., throughout the year. Joseph R. Caldwell, Carl F. Miller, and Ralph S. Solecki, archeologists, were based at that office, although Mr. Solecki did not work full time for the Surveys.

Mr. Caldwell and Mr. Miller left Washington on July 7 for Cartersville, Ga., where they started an excavation program within the area to be flooded by the Allatoona Reservoir. Mr. Miller completed part of the project early in December and returned to Washington, while Mr. Caldwell continued digging until early in February, when he went to Athens, Ga., to establish a field laboratory and study the material obtained during the excavations. Facilities for the laboratory at Athens were provided by the University of Georgia. During the first week in August Mr. Miller was temporarily detached from the Allatoona investigations and sent to Louisiana to make a preliminary reconnaissance at the Bayou Bodcau Reservoir. Except for a week in May when he visited archeological sites at Chester's Island and Floyd's Island in the Okefenokee Swamp, Mr. Caldwell spent the remainder of the fiscal year at Athens preparing his report, "A Preliminary Report on Excavations in the Allatoona Reservoir," which was published in *Early Georgia*, vol. 1, No. 1, and a manuscript pertaining to the Rembert Mounds on the Savannah River, which will be published in the first volume of the River Basin Surveys Papers.

After his return to Washington Mr. Miller devoted most of his time to a study of the material and information he had obtained at the Allatoona Reservoir and in the preparation of his portion of the report on the project. He also served as assistant to the Director, and during such times as the latter was absent from the office took charge of the operations. In June he went to the Buggs Island Reservoir, on the Roanoke River in southern Virginia, to excavate a large village and burial site that was being destroyed by construction within the area. During the year Mr. Miller completed and published five manuscripts on his work in the Southeast.

Mr. Solecki, who had been transferred to the Smithsonian Institution's staff the previous May to conduct an archeological reconnaissance in northern Alaska, returned to duty with the River Basin Surveys on September 11. In November he proceeded to Ohio, where he made a brief reconnaissance of the proposed Deer Creek and Paint Creek Reservoirs in the Scioto Reservoir basin near Chillicothe. During the remainder of the fiscal year he prepared a detailed report on the excavation of the Natrium Mound, 10 miles north of New Martinsville, W. Va., which he had dug during the winter of 1948-49.

California.—In May, Albert Mohr and J. Arthur Freed, field as-

sistants, made surveys of the Burns, Bear, and Owens Reservoirs of the Merced group, in the San Joaquin Valley. Nineteen sites were located in the three projects, but as all of them are of little significance no additional work has been recommended for them. In June, Mohr and Freed made a survey at the Cachuma Reservoir on the Santa Ynez River, near Santa Barbara. They located 18 sites and at the end of the fiscal year Mohr was making preparations to dig a series of test trenches in two of them.

Franklin Fenenga joined the River Basin Surveys as archeologist on June 19 and initiated a series of excavations at the Terminus Reservoir on the Kaweah River in the Central Valley. That area is particularly important because it was at the boundary of the territories of the Wikchamni division of the Yokuts of the San Joaquin Valley and of the Balwisha group of the Mono Indians. The archeological materials from the sites should provide important information on the problem of cultural contact and diffusion between the different tribes.

Columbia Basin.—Work in the Columbia Basin was continued under the direction of the field headquarters at Eugene, Oreg., where the University of Oregon provided laboratory and office space. Douglas Osborne, acting field director, was in charge of the program in that area until he resigned on September 3 to accept a position with the University of Washington. Joel L. Shiner was appointed to succeed him and continued as acting field director throughout the remainder of the year.

During August excavations were carried on in the McNary Reservoir area, with Washington State College cooperating in the project. Eight sites were tested or excavated on the south side of the Columbia River between Umatilla Rapids and Techumtas Island, and in addition further work was done at one of the sites excavated during the previous fiscal year. Survey reports had indicated that at two of the locations there probably were remains beneath a layer of volcanic ash. Digging there, however, failed to produce any evidence for such an occupation. Information from other sites investigated demonstrated that there were at least two cultural horizons along that portion of the river. The data seem to indicate that the older inhabitants made most of their implements of basalt while the later ones used chalcedony for the most part. The economy of the two groups appears to have been basically the same, although the earlier was less complex than the later. This is indicated by greater dependency on shellfish and a tendency toward sporadic occupation and a wandering life.

During September Charles C. Case, Jr., and Robert C. Salisbury, field assistants, surveyed 11 proposed reservoirs in the Willamette

Valley, viz, Dexter, Hills Creek, Cougar, Blue River, Gate Creek, Green Peter, Cascadia, Wiley Creek, Holly, Falls Creek, and White Bridge. The Big Cliff, which had been surveyed by Osborne the previous spring, was revisited. Probably because of the extreme steepness of the terrain and the dense cover of timber, nothing of archeological interest was found. It seems likely that the small tributary canyons in which those reservoirs will be located were never used by Indians except for temporary hunting and fishing grounds.

From the Willamette area, Case and Salisbury proceeded to the Heise-Roberts project on the Snake River in southeastern Idaho. That project consists mainly of bank-control work and when completed will not flood any of the adjacent area. Careful examination of the terrain to be disturbed by the construction work failed to reveal any archeological remains, and so further work at that location will not be necessary. From there the survey team went to the Crow Creek Reservoir near the Idaho-Wyoming border. Careful search of the area to be flooded by that project failed to reveal any archeological sites, and no further investigations will be required. From Crow Creek, Case and Salisbury returned to the Post Reservoir, which will be on the Crooked River, 10 miles east of the town of Post, Oreg. That district was occupied at one time by small bands of the northern Paiute, and since their economy was based on hunting and gathering, they spent little time in any one spot. Consequently, only three small camp sites were found in the area that will be flooded. At all three the archeological materials were found to occur only on the surface, and no further work has been recommended for that reservoir.

During the fall and winter months Shiner processed the materials from the McNary excavations and prepared the preliminary appraisal reports on the results of the surveys. In collaboration with Douglas Osborne, a preliminary report was written, giving the results of the excavation program in the McNary Reservoir. In February, Mr. Shiner, with a party of students from the University of Oregon, excavated a small cave east of The Dalles where the relocation of a highway was destroying archeological material. This project was in cooperation with the University of Oregon, which provided the student labor and assumed all the expenses of the project. An interesting series of artifacts was obtained, showing a sequence of types for the area.

In the early part of June Mr. Shiner made an inspection trip to the Cascade Reservoir on the Payette River, Idaho, to determine the condition of an archeological site where excavations were planned. On his arrival there he found that the water in the reservoir had risen

much more rapidly than contemplated and that there was no possibility for archeological work. From the Cascade Reservoir he returned to the McNary Reservoir to inspect the sites where work was to be done during the summer field season.

Richard Daugherty joined the River Basin Surveys staff as archeologist on June 12 and proceeded to the O'Sullivan Reservoir, near Moses Lake, Wash. Excavations were carried on at the O'Sullivan Reservoir in the summer of 1948 by Mr. Daugherty and the investigations this year were a continuation of the previous program. Daugherty began work in a village site and at the close of the fiscal year had excavated the remains of several pit houses and accompanying midden deposits.

Douglas Osborne rejoined the River Basin Surveys on June 15 as a consulting archeologist and took charge of the general excavation program in the Columbia Basin. He proceeded with George Cheney and S. J. Tobin, who joined the Surveys on June 16 as archeologists, and their parties to the Chief Joseph and Equalizing Reservoirs in Washington. Cheney began work at the Chief Joseph Reservoir on June 19 and from then until the close of the fiscal year was occupied in the excavation of village sites. Tobin's party at the Equalizing Reservoir began the excavation of a large cave on the same date. The cave, although its floor was littered with huge blocks that had fallen from the ceiling, gave evidence of considerable occupation, and numerous specimens of netting, cordage, basketry, and other perishable material were found there. Osborne returned to Eugene, and then proceeded with a party to the McNary Reservoir, where he began a series of excavations in sites lying farther upstream from those investigated during previous seasons. At the close of the fiscal year his party was busy digging house pits and midden deposits.

A survey party consisting of George Coale, Stewart Peck, and Charles Farrell began a reconnaissance of the John Day Reservoir on the Columbia River June 27 and at the close of the fiscal year had located a number of important sites.

Georgia.—The bulk of the work done in Georgia was at the Allatoona Reservoir on the Etowah River, near Cartersville. During the period from July to February, Joseph R. Caldwell excavated 6 sites and tested 10 others. From July to December, Carl F. Miller excavated 5 sites and tested 9 others. As a result of the investigations, it is now possible to outline a new sequence of cultural stages in the Etowah River area. At least 10, and probably 11, different periods were identified, extending from the historic Cherokee of about 1755 back to a pre-pottery period when the people depended for the most part on hunting and food gathering for their sustenance. The various periods as outlined on the basis of the investigations have been named

Galt, which is that of the historic Cherokee; Brewster and Lamar, which probably represent Creek occupation; Savannah and Etowah, which pertain to the same basic Muskogean stock but have not been identified as to the specific tribes; and the Woodstock period, which has not yet been correlated with any specific peoples but which is significant because it was characterized by a fortified village having circular palisades with towers and is the first where there is evidence for the growing of corn. The preceding period has been designated the Cartersville and is identified by a distinctive type of stamped pottery decoration and indications that the people had become at least semisedentary. The next preceding period was one represented by a site excavated by Mr. Miller but was not found by Mr. Caldwell, who did not include it in his sequence. Mr. Miller has tentatively designated the period as the Acworth. It was represented by the remains of a village containing some 60 round structures of varying sizes. Definite indications of Hopewellian influences were found in this horizon. The pottery was a plain, well-polished ware that preceded the introduction of stamped wares in the area. The next period recognized by both Caldwell and Miller is one designated the Kellogg. It was characterized by a semisedentary hunting and gathering culture. There was great use of storage pits, and a variety of acorns and nuts were recovered from them. Apparently it was during this period that the bow and arrow appeared in the Allatoona region. Antedating the Kellogg was a period called Stallings, which is represented only by scattered finds of potsherds from a fiber-tempered pottery. The oldest of the sequence, which tentatively has been designated pre-pottery, preceded the Stallings. The pre-pottery stage may represent several periods and cover a long duration of time. During that stage of the occupation of the area, the people had no pottery, no pipes, no agriculture, and possibly no houses. At least no evidence was found indicating any type of structure. The economy was basically hunting and gathering, and the chief weapon probably was a javelin hurled with a spear thrower.

Louisiana.—The only work done in Louisiana during the fiscal year consisted of the reconnaissance made by Carl F. Miller at the Bayou Bodcau project on the Red River, northeast of Shreveport. He found that although there are archeological remains in that district, none of them occur in the area to be involved by the work of the Corps of Engineers.

Missouri Basin.—As in previous years, the program in the Missouri Basin was supervised and directed from the field headquarters at the University of Nebraska, in Lincoln. From July 1 until the end of December, Dr. Waldo R. Wedel was in charge of the program. His promotion to the position of curator of the division of archeology,

United States National Museum, made it necessary for him to withdraw from the River Basin Surveys activities, and on January 23 Paul L. Cooper was designated as acting field director.

Delay in the passage of the 1950 appropriation bill greatly reduced field work in the Missouri Basin during the summer of 1949 and prevented completion of the program originally set up for the fiscal year. However, it was possible to make surveys at the Onion Flat, Soral Creek, and Raft Lake Reservoirs in the Big Horn River basin in Wyoming during July, and to initiate an excavation program in the Angostura Reservoir in South Dakota. Nothing of archeological significance was noted in the three reservoirs, and no further work is recommended for them.

The investigations at the Angostura Reservoir continued from early in July until November and were resumed in May. Though the final results of the excavations will not be known until it is possible to study all the materials obtained, it may be said that the sites where digging was done represent a number of different cultures, most of them indicating pre-pottery-making peoples. At two of them, however, evidence was obtained of two different pottery-making groups. At one of the sites the occupation level was so deeply buried that it was necessary to use a bulldozer to remove the sterile overburden. Material from that particular site indicates a period of considerable antiquity. Tentative correlations suggest that it probably is comparable in age to some of the so-called Yuma remains in other parts of the Plains area.

Other field work accomplished during the 1949 season was an 18-day reconnaissance in the Oahe Reservoir area in South Dakota. Preliminary surveys had been made there in previous years, but during the reconnaissance in November more than 50 sites, many of them previously unrecorded, were visited.

Active field work was resumed in June when a paleontological party proceeded to the Angostura Reservoir, the Boysen and Anchor Reservoirs in Wyoming, and the Canyon Ferry project in Montana. Important fossils were recovered from the latter area. On June 7 excavations were started in the Garrison Reservoir in North Dakota, in the Tiber Reservoir in Montana, and later in the month at the Oahe project in South Dakota. All those activities were proceeding satisfactorily at the end of the fiscal year.

During the fall and winter months considerable work was done in the laboratory. Eight preliminary reports were written and mimeographed for distribution to the cooperating agencies. In all, 16,938 specimens collected from 146 sites in 16 reservoir areas were cleaned and cataloged. Fifty-six maps were drawn and 1,318 negatives processed. The negatives include field photographs, black-and-white

negatives of color transparencies, and laboratory photographs. Two hundred and six transparencies were cataloged and filed; 78 enlargements were printed and mounted; and 1,782 black-and-white contact prints were made, cataloged, and filed. More than 4,000 photographic copies of archeological records were made to bring the basic record file up to date. A considerable number of animal bones taken from archeological sites were identified and there was some restoration of fragmentary pottery.

G. Ellis Burcaw joined the staff as an archeologist on May 31 and left Lincoln on June 7 for the Garrison Reservoir in North Dakota, where he began a series of excavations at the so-called Rock Village. That site, one of the farthest upstream of the known fortified earth-lodge villages, was yielding considerable quantities of artifacts, including some European trade material, as work progressed at the close of the fiscal year.

Early in the fiscal year Paul L. Cooper devoted his time to studying materials pertaining to the archeological remains in the Oahe and Fort Randall Reservoirs. During September he made two brief trips to the Angostura and Oahe Reservoirs and late in October accompanied Dr. Frank H. H. Roberts, Jr., Director of the River Basin Surveys, on a visit to the excavation projects at the Angostura Reservoir and to inspect sites in other areas. During November he made a reconnaissance along the east side of the Missouri River in the Oahe Reservoir area. In December he accompanied Dr. Gordon Baldwin, of the National Park Service, Dr. Carlyle Smith, of the University of Kansas, and Wesley Hurt, of the University of South Dakota, on a trip to the Fort Randall and Oahe Reservoirs in South Dakota for the purpose of selecting sites for excavation by the Universities of Kansas and South Dakota during the summer of 1950. On January 23, 1950, he was designated acting field director of the River Basin Surveys, and thereafter his activities were mainly concerned with planning and supervising the headquarters and field activities of the organization.

Robert B. Cumming, Jr., archeologist, served throughout the year as laboratory supervisor at the Lincoln headquarters. During such time as the acting director was absent from the office, he assumed administrative responsibility for continuing its operations. In addition he carried on research work on the skeletal material from the Medicine Creek and Harlan County Reservoirs and prepared an appendix on the skeletal remains from the Woodruff ossuary for the technical report on the ossuary. He also did some work on the human remains from ossuaries in Nebraska.

Walter D. Enger, Jr., archeologist, joined the River Basin Surveys staff on May 31 and left Lincoln on June 9 to begin the excavation of

sites to be flooded by the proposed Tiber Reservoir on the Marias River in Montana. Previous surveys in that area had shown three types of sites, consisting of buried occupational levels exposed along the edges of the river terraces, surface sites on the river terraces, and tipi-ring sites on top of the plateau surrounding the reservoir. Because of the nature of the cultures represented, the artifact yield and the work accomplished before the end of the fiscal year was small, but considerable information was being obtained about the sequence of cultures and the general aboriginal characteristics of the area.

Jack T. Hughes, archeologist, left Lincoln on July 7 and proceeded to the Angostura Reservoir in South Dakota, where he initiated a series of excavations. Hughes continued in charge of that project until September when he resigned from the River Basin Surveys to return to Columbia University for further academic work. Mr. Hughes prepared a report on the results of the Angostura work obtained while he was in charge of the field party.

Donald J. Lehmer, Jr., archeologist, joined the Missouri Basin staff on June 1. He left Lincoln on June 9 with G. Ellis Burcaw and proceeded with him to the Tiber project where he assisted in establishing headquarters. From there he returned to Pierre, S. Dak., and on June 19 began the excavation of a stratified earth-lodge village in the area of the Oahe Dam approach channel. By the end of the fiscal year his party had identified house remains attributable to both the Arikara and the Mandan.

George Metcalf, field and laboratory assistant, spent the period from July 22, 1949, to November 7, 1949, with the field party at the Angostura Reservoir. During the fall and winter months he assisted in the analysis of the material from the Medicine Creek Reservoir and in the preparation of the report for the excavations made there during the previous fiscal year. He also made a study of ceramic materials from Upper Republican sites which are in the collections of the Nebraska State Historical Society at Lincoln. Metcalf left Lincoln on May 19 with the Wheeler party and at the close of the fiscal year was working at the Angostura Reservoir.

Robert L. Shalkop joined the staff as an archeologist on June 28, and at the end of the fiscal year was preparing to leave with a reconnaissance party to survey a number of reservoir projects in Montana and Wyoming.

James M. Shippee, field and laboratory assistant, was a member of the field party at the Angostura Reservoir from early in July until early in November. During the fall and winter months he devoted considerable time to the restoration of pottery vessels and the processing of other specimens from the Angostura excavations. During the spring months most of his time was occupied in the preparation of

field equipment to be used by the various parties during the summer months.

At the beginning of the fiscal year Richard P. Wheeler, archeologist, was engaged in preliminary archeological surveys of the Onion Flat, Soral Creek, and Raft Lake Reservoirs, in the Big Horn River basin, Fremont County, Wyo. He returned to the Lincoln headquarters on July 11 and spent the time from then until the middle of August preparing reports on the reservoir areas examined over the period in which his party had been in the field. In August he joined the Angostura field party and after the departure of Mr. Hughes took full charge of the operations. From September 4 to November 7, Wheeler and his crew partially excavated or tested and mapped 11 sites. He returned to Lincoln in November and devoted the time from then until the middle of April in analyzing artifacts, supervising the drawing of site maps and profiles, and preparing an outline and notes for the final report on the Angostura investigations. On April 19 he made a 5-day trip to the Angostura Reservoir to make plans for the excavations for the coming season. One month later he returned to the Angostura Reservoir with a field party and from then until the end of the fiscal year he excavated and tested two sites and supervised the removal of overburden with a bulldozer at two areas at a third site. The use of mechanized equipment in this particular instance was made necessary by the fact that the occupation level occurs beneath from 9 to 10 feet of sterile deposits, and there was not sufficient time to remove them by the usual hand methods. The materials found in the deeply buried level indicate an early hunting culture.

Dr. Theodore E. White, paleontologist, spent the early months of the fiscal year in the laboratory at Lincoln identifying osteological material obtained from archeological sites and in preparing a report on the physiography of the Angostura Reservoir. He worked in Texas in November and December. In January he was transferred to the Smithsonian Institution staff and was sent to Panamá. He returned to duty with the River Basin Surveys in May. He left the Lincoln headquarters on June 15 and proceeded to the Boysen Reservoir area in Wyoming, where he prospected for vertebrate fossils until June 15. He then moved on to the Anchor Reservoir area where he prospected the Upper Permian and Lower Triassic deposits. On June 21 he moved to the Canyon Ferry Reservoir area in Montana, and spent the time prospecting the Oligocene and Miocene deposits. Two of the Oligocene localities produced abundant specimens, mostly small mammals, while three new localities were discovered in the Miocene deposits. Material obtained from two of the new localities definitely establishes the presence of both Lower and Middle Miocene

deposits in the area. During the course of this work, Dr. White was assisted by Prentiss Shepherd, Jr., a student at Harvard University, and William C. Harrup, Jr., a student at Columbia University.

Ohio.—Field work in Ohio was restricted to brief visits to the proposed Deer Creek and Paint Creek Reservoirs on two tributaries of the Scioto River, near Chillicothe. Mr. Solecki, of the River Basin Surveys, went to Ohio in November and, in company with Clyde B. King, superintendent of Mound City National Monument, and Raymond Baby, archeologist of the Ohio State Archeological and Historical Society, Columbus, determined that no sites of archeological significance would be inundated by the proposed reservoirs. During the course of the reconnaissance, Mr. Solecki examined three features on Deer Creek and two nearby on Spruce Hill, which were purported to be Norse iron furnaces, but was unable to find anything that could be construed as conclusive proof that the remains represented ancient iron furnaces. The opinion was that the features probably had been lime kilns dating from the early Colonial period in the area.

Texas.—The River Basin Surveys in Texas continued to operate from the base and headquarters furnished by the Department of Anthropology of the University of Texas at Austin. Surveys were begun and completed at the Belton Reservoir on the Leon River, at the Canyon Reservoir on the Guadalupe River, and at the Texarkana Reservoir on the Sulphur River, near the town of Texarkana. The work at the Belton Reservoir resulted in the location of 43 archeological sites. Five of them were found to lie outside the reservoir area. Twelve of the remaining are rock-shelter sites, 12 are open occupational areas, and 4 are a combination of the two forms. The remainder consist either of burned rock middens or deeply buried middens. Testing was done in five sites, and a number of interesting artifacts were recovered. However, it was discovered that during the course of the years most of the sites in the area had been looted by commercial collectors and so little remains that further investigations are not warranted. Such evidence as was found during the reconnaissance and testing indicated that the Belton district probably was occupied by people of the Round Rock focus over a period of many centuries.

At the Canyon Reservoir, 20 archeological sites were located and recorded. Five of them are large open sites, 3 are small rock shelters, 1 is a deeply buried occupation level, 1 is a subterranean cavern, and the remaining 10 are small open sites containing a single burned rock midden in each. The area is one from which only meager archeological information is available and for that reason 8 of the sites have been recommended for excavation and complete analysis.

The Texarkana reconnaissance resulted in the location of 50 archaeological sites, all of which are open occupational areas. At three of them there are small artificial mounds of the variety which has been called "Capped Ridge." Ten of the sites appear to belong to a non-pottery horizon, probably the Balcones phase. Seventeen are large village areas characterized by potsherds and appear to range in time from Early Gibson Aspect to Middle Fulton Aspect. At least two sites are related to the Coles Creek culture. The remainder are small sites of indeterminate affiliation. Of the total, 16 sites have been recommended for extensive excavation and analysis.

Excavations were carried on at the Whitney Reservoir from March 6 to June 18. During that period five Indian sites—three rock-shelter and two open sites—were extensively excavated and two historic sites were studied and recorded. One shelter called Pictograph Cave contained material from two different periods, the first probably dating before A. D. 1200 and the second sometime subsequent to that date but pre-Columbian. The early occupation is comparable in many respects to the Round Rock focus in Texas, while the second has not yet been correlated with other remains. The data obtained from the shelter give interesting information pertaining to changes in diet and population density during the two periods of occupation. The second, known as Buzzard Shelter, is not far from the first, and also gave evidence of an early occupation in the lower depths of the fill. The later occupation in the shelter suggests certain similarities to that of the Toyah focus. While there is considerable similarity between the cultural sequence found in the two shelters, there are specific differences in artifact types and stratigraphic proportions. The third shelter, known locally as Sheep Cave, is the largest of the three, and the material from it agrees in the main with that from the other two. Five flexed burials were found there, however, and study of the physical type represented should throw some light on the relationships of the people.

Three weeks were spent in the excavation of a small occupational area on the second terrace of the Brazos River at the Steele site. The evidence of occupation on the surface covers about an acre in extent and it is underlain by an unknown number of occupational levels of considerably greater extent. Traces of occupation extend to a depth of at least 15 feet, and it will be necessary to use mechanical equipment to excavate a deep trench in order to make stratigraphic studies. The site appears to be a significant one in that the most recent occupation was prior to the advent of pottery and the bow and arrow in that area.

The Stansbury site, the location of a historic Indian village, was the fifth area excavated. Material from it includes trade items of French,

English, and American origin. The occupation probably began in the mid-eighteenth century, or perhaps somewhat earlier, and lasted until 1869. House patterns with compact floor, post holes, central fire hearth, and bell-shaped cache pits were found. In general, it may be said that the site shows relationship with Taovayas site of Spanish Fort. It is located near the site of Towash Village, one of the historic sites studied. This village was an early white settlement dating from the 1840's to the present time. The first dam and bridge on the Brazos River were located there, and their remains, as well as those of the old stone store and church, are still to be seen. Measurements and photographs were taken in order to make scale drawings of the buildings.

The other historic site studied was that of Fort Graham, a frontier post dating 1849-54. The outlines of one of the buildings, as well as several other features, were located. It also was determined that the "Village of the Caddoes," visited by Ferdinand Roemer in 1846, was situated at the site of Fort Graham.

Excavations got under way at the Lavon Reservoir on June 19 in the Hogge Bridge site, one of 11 situated along the east fork of the Trinity River. Each of the sites contains a large circular pit, which is a feature peculiar to the area. Digging was started in one of the large pits in order to determine what their purpose may have been. By the end of the fiscal year, the southwestern quarter of the pit in the Hogge Bridge site had been cleared and the original surface uncovered. The pit was 10 feet deep, 65 feet in diameter on the inside, and had a rim of dirt from the original excavation piled around the periphery measuring 90 feet from crest to crest. The floor proved to be concave, and no post holes or evidences of a structure had been found by the end of the year. Along the east rim of the pit was a burial area, and on the inner slope of the south side of the pit a bear burial was uncovered. Potsherds indicate that the site probably dates between A. D. 1200 and 1500, but its cultural affiliations had not yet been determined.

During November and December Dr. Theodore E. White prospected the Upper Cretaceous deposits in the Lavon Reservoir for vertebrate fossils. A number of specimens were located, but time permitted the removal of only two. One consisted of a small mosasaur (unident) skull and the skull of a large mosasaur (*Tylosaurus?*).

During the time when he was not in the field, Robert L. Stephenson, archeologist, prepared reports on the various surveys which he had made and processed the specimens in the laboratory at Austin. In November he attended the Seventh Conference for Plains Archeology and presented a paper on the work he had been doing in Texas. In May he attended the meetings of the Society for American Archaeology

at Norman, Okla., and took part in the discussions held there. At the close of the fiscal year he was occupied with the excavations at the Lavon Reservoir.

Edward B. Jelks was appointed temporary assistant at the laboratory in October and in February was made assistant field archeologist. He helped Mr. Stephenson in the processing of specimens until March 6, when he proceeded with the party to the Whitney Reservoir and assisted in the excavation program throughout the course of the work. During such times as Mr. Stephenson was not with the party, Mr. Jelks was in full charge. On June 12 he was appointed archeologist and proceeded to the Lavon Reservoir, where he was at work at the end of the fiscal year.

Cooperating institutions.—As in previous years, numerous State and local institutions cooperated with the River Basin Surveys. Space for field offices and laboratories for units of the Surveys were provided by the Universities of Georgia, Nebraska, Oregon, and Texas. The Universities of Oregon and Washington and Washington State College joined forces with the Surveys both in reconnaissance work and in excavations at the McNary, O'Sullivan, Equalizing, and Chief Joseph Reservoirs in the Columbia Basin, while the University of Georgia took over the responsibility for the excavation of one large site in the Allatoona Reservoir in Georgia, and for a series of surveys as well as excavations along the Flint River in the southern part of that State. The University of Missouri and the Missouri Archeological Society continued their cooperation in making surveys in a number of proposed reservoir areas and in conducting some excavations. During the early months of the fiscal year, the Museum of Natural History of the University of Kansas, the Laboratory of Anthropology of the University of Nebraska, the State Museum of the University of Nebraska, and the Nebraska State Historical Society continued excavation projects that had been started toward the close of the preceding year. The University of Oklahoma continued work in the Fort Gibson Reservoir in the summer of 1949, and in June of 1950 returned to the area for further work.

Late in the fiscal year a program developed by the National Park Service, whereby various scientific agencies would carry on salvage work in proposed reservoir areas, got under way. On the basis of agreements between the National Park Service and the agencies concerned, certain funds were made available to the latter to help cover the expense of the investigations. The River Basin Surveys participated in that program in a consultative capacity only. The final results of the work accomplished, however, will be correlated with those of the Surveys.

INSTITUTE OF SOCIAL ANTHROPOLOGY

(Report prepared by GORDON R. WILLEY)

General statement.—The objectives of the Institute of Social Anthropology are anthropological research on the community life of rural peoples of Latin America and the training of Latin American nationals in the methods and principles of modern social anthropology. The aim is to inform both the social scientist and layman in the United States concerning little-known peoples of other parts of the world and to build up in various Latin American countries a corps of professionally trained scientists and friends.

During the past year the Institute was financed by transfers of funds from the Department of State, totaling \$82,510, from the appropriation "International Information and Education Activities, 1950." As in the previous year, long-term planning has been done on a very tentative basis because of budget uncertainties for the future. Early in the fiscal year reorganizations in Department of State technical-aid-type programs called for a reappraisal of the Institute's goals and programs. With the Point IV foreign aid scheduled to take the place of many of the projects of the former Committee for Scientific and Cultural Cooperation, the question was raised as to whether the work of the Institute should come within this new organizational framework. The decision of the Institute, in keeping with the general policy of the Smithsonian Institution, was that the Institute should continue with basic research and teaching and not enter directly into the field of applied social science. Nevertheless, the Institute, through the office of the Director, served in an informal consultative capacity to the Program Analysis and Reports Branch of the Interdepartmental Committee and to the Point IV successor of this committee. Such consultation has included recommendations for anthropological aid and personnel for Point IV work, conferences with the representatives of other governmental agencies considering technical assistance programs, and informal memoranda from our field representatives on features of local native life that provide a background for economic development programs.

The regular assignments and program of the Institute continued as formerly in the Washington office, and in the field stations in Brazil, Colombia, México, and Perú.

Washington office.—Dr. George M. Foster, Director, served from July 1 until September 3, assuming leave status at the end of this period to conduct privately sponsored research in Spain. Although these investigations in Spain are not officially connected with the Institute of Social Anthropology program, they bear directly upon it scientifically in view of the close historical relationships between Spain

and Latin America. Dr. Gordon R. Willey, on loan from the Bureau of American Ethnology, was Acting Director for the remainder of the year. Miss Lois C. Northcott, formerly secretary to the Director, became administrative assistant in November 1949.

Upon the recommendation of the Director, Dr. José M. Cruxent, Director of the Museo de Ciencias Naturales, Caracas, Venezuela, visited the United States on a Department of State grant-in-aid. He remained during August and September, traveling within this country to various museums and universities.

In February, Dr. Willey began an extended tour of Institute field posts and, en route, visited other Latin-American countries to renew professional contacts and to discuss scientific and local academic problems with Latin-American colleagues. Mexico City, Guatemala City, Panamá, Bogotá, Quito, Lima, Santiago, Buenos Aires, São Paulo, Rio de Janeiro, and Caracas were included on this trip.

Brazil.—Drs. Donald Pierson, sociologist, and Kalervo Oberg, social anthropologist, continued their research and teaching activities in cooperation with the Escola Livre de Sociologia e Política in São Paulo. Dr. Pierson, after a 2-months' consultation in the United States, assumed duties in the Escola Livre de Sociologia e Política as dean of the graduate section. In connection with these duties he trained graduate students in problems of academic administration. In addition he taught courses in sociology and social anthropology, supervised masters theses in social anthropology, and was engaged in writing and preparing manuscripts in social anthropology and sociology. In April Dr. Pierson represented the Smithsonian Institution at Brazil's National Indian Week celebrations in Rio de Janeiro. at the request of the Brazilian Embassy. During May and June, Dr. Pierson, accompanied by graduate students, undertook an intensive social anthropological survey of the large and important São Francisco River Valley. This field work was sponsored by the federal government of Brazil as well as by the Institute of Social Anthropology. A survey report is anticipated that will be of particular interest for the Brazilian Government's economic development plans for the São Francisco Valley.

Dr. Kalervo Oberg, accompanied by a student assistant, spent the months of July and August in the northwestern Mato Grosso among the Nambicuará, Iranxe, and other Indian groups. These tribes, some of the most primitive in the world, lead a completely isolated life, and there is very little scientific literature on them. He returned to São Paulo late in August and resumed teaching, devoting his research time to the preparation of a manuscript on the Mato Grosso field work. Dr. Oberg delivered the address at the Escola Livre de

Sociología e Política for the commencement exercises held in March. He spent May and June in the United States on consultation.

Colombia.—In Colombia, Dr. Raymond E. Crist, cultural geographer on leave from the University of Maryland, represented the Institute at the Universidad del Cauca, Popayan. For the past year Dr. Crist was in Colombia only for the months of July through August, returning to the United States in September. During this stay, which was a continuation of an appointment made in 1949, Dr. Crist and a group of Colombian scientists and graduate students made a survey trip into the western section of the Department of Cauca for the purpose of studying land utilization and agricultural and animal-husbandry techniques. In August he accompanied Dr. A. C. Whiteford of Beloit University on a field trip among the Guambiano Indians, and shortly thereafter he visited the lower Eastern Cordillera on a geographic survey. Dr. Crist was especially cited to the Secretary of State by the assistant public affairs officer in Bogotá for the professional and personal success of his stay in Colombia.

México.—Dr. Isabel T. Kelly, Institute representative assigned to the Escuela Nacional de Antropología in Mexico City, divided her time between teaching and the writing of the first volume of an ethnography of the Totonac Indians. This work was completed in March, and since then Dr. Kelly has continued with preparation of the second volume. She also carried on a research seminar for Mexican graduate students in the writing and general preparation of scientific monographs.

The United States-sponsored Benjamin Franklin Library in Mexico City exhibited some 80 photographs taken by Dr. Kelly during her work among the Totonac Indians, and these photographs were later borrowed by the Mexican Government for displays in Jalapa, Monterrey, Morelia, and Oaxaca. Dr. Kelly's activities have been favorably publicized by a feature article released in the Mexican popular weekly magazine *Nosotros*.

In connection with the Washington office's attempt to demonstrate the utility of anthropology for the Point IV type of economic development program, Dr. Kelly prepared an analysis of possibilities for public housing in the tropical coastal area of the Gulf of Mexico. This was written from the point of view of the native cultures involved, with which Dr. Kelly is expertly familiar, and points up the conflicts and difficulties to be overcome in implanting technological ideas on alien societies. During September Dr. Kelly was in the United States for consultation.

Perú.—The 1950 year opened with Dr. George A. Kubler, on leave from Yale University, as the Institute's representative attached to the Peruvian Instituto de Estudios Etnológicos in Lima. Dr. Kubler, an

authority on the Colonial Period in Perú, continued with his research on archival material in the Department of La Libertad, Trujillo, as well as in the Lima archives. Consultation with students in anthropology and history was also maintained. Dr. Kubler returned to the United States in September. A manuscript covering a part of Dr. Kubler's work in Perú, "The Indian Caste of Perú, 1795-1950," an analysis of population and racial attitudes, was submitted for publication in April.

Ozzie G. Simmons, current representative in Perú, arrived in Lima in November. Mr. Simmons offered a course on American ethnic groups and acculturation in the Peruvian Instituto de Estudios Etnológicos and began field investigations at the town of Lunahuaná. Studies at this community, initiated in February with the aid of a student assistant, have run throughout the year and will extend into 1951. Coincident with this research Mr. Simmons is collaborating in a seminar on social anthropological field methods. He has also aided in a questionnaire project conducted by the Peruvian National School of Social Work among groups of highland Indians who have recently moved to the vicinity of Lima in response to industrial opportunities. Quite importantly, he has been instrumental in advising the Peruvian Ministry of Public Health to add a Peruvian social anthropologist to their staff for work in the Department of Ica. This has created an excellent job opportunity for a Peruvian trained by us and has shown the way for further employment of our trainees in governmental departments.

EDITORIAL WORK AND PUBLICATIONS

There were issued one Annual Report and one Bulletin volume (Handbook of South American Indians), and one Publication of the Institute of Social Anthropology as listed below:

Sixty-sixth Annual Report of the Bureau of American Ethnology, 1948-1949. 34 pp.

Bulletin 143. Handbook of South American Indians. Julian H. Steward, editor. Volume 5, The comparative ethnology of South American Indians. xxvi+818 pp., 56 pls., 190 figs., 22 maps. 1949.

Institute of Social Anthropology Publ. No. 10. Nomads of the Long Bow: The Siriono of eastern Bolivia, by Allan R. Holmberg. 104 pp., 7 pls., 4 charts, 1 map. 1950.

The following publications were in press at the close of the fiscal year:

Bulletin 143. Handbook of South American Indians. Julian H. Steward, editor. Volume 6, Physical anthropology, linguistics, and cultural geography of South American Indians.

Bulletin 144. The northern and central Nootkan tribes, by Philip Drucker.

Bulletin 145. The Indian tribes of North America, by John R. Swanton.

Bulletin 146. Chippewa child life and its cultural background, by Sister M. Inez Hilger.

Bulletin 147. Journal of an expedition to the Mauvaises Terres and the Upper Missouri in 1850, by Thaddeus B. Culbertson. Edited by John Francis McDermott.

Bulletin 148. Arapaho child life and its cultural background, by Sister M. Inez Hilger.

Institute of Social Anthropology Publ. No. 11. Quiroga: A Mexican Municipio, by Donald D. Brand.

Institute of Social Anthropology Publ. No. 12. Cruz das Almas: A Brazilian village, by Donald Pierson.

Institute of Social Anthropology Publ. No. 13. The Tajin Totonac: Part 1. History, subsistence, and technology, by Isabel Kelly and Angel Palerm.

Institute of Social Anthropology Publ. No. 14. The Indian caste of Peru, 1795-1950: A population study based upon tax records and census reports, by George Kubler.

Publications distributed totaled 19,116 as compared with 19,660 for the fiscal year 1949.

LIBRARY

The total number of volumes accessioned in the library is 34,838, an increase of 119 volumes over the fiscal year 1949.

ARCHIVES

The largest collection of Indian photographs acquired by the Bureau in many years was obtained during the past year when the Library of Congress gave permission to copy pictures submitted long ago for copyright purposes. These pictures, made more than 50 years ago, show many famous Indians whose portraits are new to the collections. Another group of 50 rare Indian photographs was received from Eddie Herman, a Sioux Indian of Hot Springs, S. Dak.

The manuscript material in the archives of the Bureau has been used by research workers both by personal visits for consultation and by correspondence.

A new manuscript of 2,380 pages, in the Fox Indian language, consisting of a vocabulary, with grammatical and linguistic notes, was donated to the Bureau by Miss Ella A. Merritt of Washington. This work was compiled by the late James Brannin, formerly connected with the United States Navy during the time (1935-42) he was stationed near the Fox Indians in Wisconsin.

COLLECTIONS

Acc. No.

175998. Surface material from aboriginal sites in Allatoona Reservoir area, Cherokee, Bartow, and Cobb Counties, northwest Georgia, collected by Joseph R. Caldwell from November 1946 to April 1947. River Basin Surveys.

Acc. No.

182578. Archeological materials, consisting of stone artifacts and potsherds, from two prehistoric shell mounds near Monagrillo, Herrera Province, Republic of Panamá, and including in the Monagrillo pottery series what is believed to be the earliest yet known from Panamá, collected by Drs. M. W. Stirling and Gordon R. Willey during the 1948 Smithsonian Institution-National Geographic Society expedition to Panamá.
182845. A collection of archeological material together with 250 geological specimens, 31 mammals, botanical specimens, 4 fish, 20 insects, and approximately 64 marine invertebrates from Cornwallis Island, the Canadian Arctic, collected by Henry B. Collins, Jr., in the summer of 1949 on the National Museum of Canada-Smithsonian Institution Expedition.
183940. 68 potsherds of various types from an archeological site, Crystal River, Citrus County, Fla., collected by Dr. Gordon R. Willey.
185245. 2 beetles, 2 lizards, 1 snake, and 1 frog from Province of Chiriquí, Panamá, collected by Dr. M. W. Stirling.
185249. About 20 specimens of Eocene invertebrate fossils from Louisiana, collected by Carl F. Miller. River Basin Surveys.
185382. 11 original oil paintings of Yahgan, Ona, and Tehuelche Indians, Argentine prisoners, and scenes of the Furlong Expedition of 1908 to Tierra del Fuego, painted by Charles W. Furlong.
185538. (Through Carl F. Miller) 12 fresh-water mollusks from northwestern Georgia, gathered in an Indian village site. River Basin Surveys.
185627. (Through Dr. Frank H. H. Roberts, Jr.) 2 mosasaur skulls collected by Dr. T. E. White from upper Cretaceous deposits of the Lavon Reservoir area, 1 mile east of Culeoka, Collin County, Tex. River Basin Surveys.
186797. 4 dictaphones and phonographs, including ones used by Alice C. Fletcher and Frances Densmore.

MISCELLANEOUS

Dr. Frances Densmore, Dr. John R. Swanton, and Dr. Antonio J. Waring, Jr., continued as collaborators of the Bureau of American Ethnology.

During the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the American Indians, past and present, of both continents. The increased number of requests from teachers of primary and secondary grades and from Scout organizations indicates a rapidly growing interest in the American Indian throughout the country. Various specimens sent to the Bureau were identified and data on them furnished for their owners. Respectfully submitted.

M. W. STIRLING, *Director.*

Dr. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the activities of the International Exchange Service for the fiscal year ended June 30, 1950:

The Smithsonian Institution is the official United States agency for the exchange with other nations of governmental, scientific, and literary publications. The International Exchange Service, initiated by the Smithsonian Institution in the early years of its existence for the interchange of scientific publications between learned societies and individuals in the United States and those of foreign countries, serves as a means of developing and executing in part the broad and comprehensive object, "the diffusion of knowledge." It was later designated by the United States Government as the agency for the transmission of official documents to selected depositories throughout the world, and it continues to execute the exchanges pursuant to conventions, treaties, and other international agreements.

The number of packages received for transmission during the year was 1,009,675, an increase over the previous year of 169,550 packages, or approximately 20 percent. The weight of the packages was 832,087 pounds, an increase of 35,387 pounds, or approximately 4.4 percent. It was only through the installation and utilization of labor-saving devices that the International Exchange Service was able to process the additional number of packages without increased personnel.

The average weight of the individual package decreased to approximately 13 ounces as compared with the average of 15 ounces for the fiscal year of 1949. This indicates that the majority of the publications now being transmitted are current publications rather than accumulated publications. A further reason for the reduction in the average weight of the individual package is to be found in the fact that more of the departments of the United States Government are using the International Exchange Service for the transmission of their periodical publications. The publications received from both the

foreign and domestic sources for shipment are classified as shown in the following table:

Classification	Packages		Weight	
	<i>Number</i>	<i>Number</i>	<i>Pounds</i>	<i>Pounds</i>
United States parliamentary documents sent abroad.....	526, 804		226, 966	
Publications received in return for parliamentary documents.....		13, 596		21, 873
United States departmental documents sent abroad.....	251, 107		220, 487	
Publications received in return for departmental documents.....		5, 955		14, 147
Miscellaneous scientific and literary publications sent abroad.....	169, 129		253, 928	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States.....		43, 084		94, 686
Total.....	947, 040	62, 635	701, 381	130, 706
Grand total.....	1, 009, 675		832, 087	

The packages of publications are forwarded by freight to the exchange bureaus of foreign countries and to addressees in foreign countries where shipment by such means is impractical by direct mail. The number of boxes shipped to the foreign exchange bureaus was 2,889, a decrease of 407 boxes from the previous year. Of the boxes shipped 841 were for depositories of full sets of United States Government documents, these publications being furnished in exchange for the official publications of foreign governments for deposit in the Library of Congress. The number of packages forwarded by mail and means other than freight was 219,471.

In spite of the fact that considerable savings in transportation continued to be effected by exporting through Baltimore rather than New York, and in spite of the advantage gained through special arrangements for shipment to Germany, the allotment for transportation was insufficient to maintain full operations for the entire year. Owing to the insufficient funds and to the fact that no shipments were made to China or Rumania, the International Exchange Service ended the fiscal year with a backlog of 145,224 pounds of publications.

Consignments are now forwarded to all countries except China and Rumania. Publications for addressees in Formosa, formerly sent through the Chinese Exchange Bureau, are now forwarded by direct mail.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The number of sets of United States official publications received by the Exchange Service to be sent abroad in return for the official publications sent by foreign governments for deposit in the Library of Congress is 99 (59 full and 40 partial sets). Changes that occurred during the year are shown in the footnotes.

DEPOSITORIES OF FULL SETS

ARGENTINA: Dirección de Investigaciones, Archivo, Biblioteca y Legislación Extranjero, Ministerio de Relaciones Exteriores y Culto, Buenos Aires.

AUSTRALIA: Commonwealth Parliament and National Library, Canberra.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

QUEENSLAND: Parliamentary Library, Brisbane.

SOUTH AUSTRALIA: Public Library of South Australia, Adelaide.

TASMANIA: Parliamentary Library, Hobart.

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

AUSTRIA: Administrative Library, Federal Chancellery, Vienna.

BELGIUM: Bibliothèque Royale, Bruxelles.

BRAZIL: Biblioteca Nacional, Rio de Janeiro.¹

BULGARIA: Bulgarian Bibliographical Institute, Sofia.

BURMA: Government Book Depot, Rangoon.

CANADA: Library of Parliament, Ottawa.

MANITOBA: Provincial Library, Winnipeg.

ONTARIO: Legislative Library, Toronto.

QUEBEC: Library of the Legislature of the Province of Quebec.

CEYLON: Department of Information, Government of Ceylon, Colombo.²

CHILE: Biblioteca Nacional, Santiago.

CHINA: Ministry of Education, National Library, Nanking, China.³

PEIPING: National Library of Peiping.³

COLOMBIA: Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA: Ministerio de Estado, Canje Internacional, Habana.

CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.

DENMARK: Institut Danois des Échanges Internationaux, Copenhagen.⁴

EGYPT: Bureau des Publications, Ministère des Finances, Cairo.

FINLAND: Parliamentary Library, Helsinki.

FRANCE: Bibliothèque Nationale, Paris.

GERMANY: Öffentliche Wissenschaftliche Bibliothek, Berlin.

Parliamentary Library, Bonn.⁵

GREAT BRITAIN:

ENGLAND: British Museum, London.

LONDON: London School of Economics and Political Science. (Depository of the London County Council.)

HUNGARY: Library of Parliament, Budapest.

INDIA: National Library, Calcutta.

INDONESIA: Ministry for Foreign Affairs, Djakarta.⁶

IRELAND: National Library of Ireland, Dublin.

ISRAEL: Government Archives and Library, Hakirya.⁶

ITALY: Ministero della Pubblica Istruzione, Rome.

JAPAN: National Diet Library, Tokyo.

MEXICO: Secretaría de Relaciones Exteriores, Departamento de Información para el Extranjero, Mexico, D. F.

¹ Changed from Instituto Nacional do Livro.

² Changed from partial set.

³ Suspended.

⁴ Changed from Kongelige Danske Videnskabernes Selskab.

⁵ Changed from Amerika Institut, Berlin.

⁶ Added during the year.

- NETHERLANDS: Royal Library, The Hague.
 NEW ZEALAND: General Assembly Library, Wellington.
 NORWAY: Utenriksdepartementets Bibliothek, Oslo.
 PERU: Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.
 PHILIPPINES: Bureau of Public Libraries, Department of Education, Manila.
 POLAND: Bibliothèque Nationale, Warsaw.
 PORTUGAL: Biblioteca Nacional, Lisbon.
 SPAIN: Biblioteca Nacional, Madrid.⁷
 SWEDEN: Kungliga Biblioteket, Stockholm.
 SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.
 TURKEY: Department of Printing and Engraving, Ministry of Education, Istanbul.
 UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
 UNION OF SOVIET SOCIALIST REPUBLICS: All-Union Lenin Library, Moscow 115.
 UKRAINE: Ukrainian Society for Cultural Relations with Foreign Countries, Kiev.³
 UNITED NATIONS: Library of the United Nations, Geneva, Switzerland.
 URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
 VENEZUELA: Biblioteca Nacional, Caracas.
 YUGOSLAVIA: Ministère de l'Education, Belgrade.

DEPOSITORIES OF PARTIAL SETS

- AFGHANISTAN: Library of the Afghan Academy, Kabul.
 BOLIVIA: Biblioteca del Ministerio de Relaciones Exteriores y Culto, La Paz.
 BRAZIL:
 MINAS GERAIS: Directoria Geral de Estatística em Minas, Belo Horizonte.
 BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.
 CANADA:
 ALBERTA: Provincial Library, Edmonton.
 BRITISH COLUMBIA: Provincial Library, Victoria.
 NEW BRUNSWICK: Legislative Library, Fredericton.
 NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.
 SASKATCHEWAN: Legislative Library, Regina.
 DOMINICAN REPUBLIC: Biblioteca de la Universidad de Santo Domingo, Ciudad Trujillo.
 ECUADOR: Biblioteca Nacional, Quito.
 GREECE: National Library, Athens.
 GUATEMALA: Biblioteca Nacional, Guatemala.
 HAITI: Bibliothèque Nationale, Port-au-Prince.
 HONDURAS:
 Biblioteca y Archivo Nacionales, Tegucigalpa.
 Ministerio de Relaciones Exteriores, Tegucigalpa.
 ICELAND: National Library, Reykjavik.
 INDIA:
 BIHAR AND ORISSA: Revenue Department, Patna.
 BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.

⁷ Changed from Cambio Internacional de Publicaciones.

INDIA—Continued

UNITED PROVINCES OF AGRA AND OUDH:

University of Allahabad, Allahabad.

Civil Secretariat, Council House, Lucknow.⁶

WEST BENGAL: Library, West Bengal Legislature, Assembly House, Calcutta.

IRAN: Imperial Ministry of Education, Tehran.

IRAQ: Public Library, Baghdad.

JAMAICA: Colonial Secretary, Kingston.

University College of the West Indies, St. Andrews.⁶

LIBERIA: Department of State, Monrovia.

MALAYA: Federal Secretariat, Federation of Malaya, Kuala Lumpur.

MALTA: Minister for the Treasury, Valleta.

NEWFOUNDLAND: Department of Home Affairs, St. John's.

NICARAGUA: Ministerio de Relaciones Exteriores, Managua.

PAKISTAN: Chief Secretary to the Government of Punjab, Lahore.

PANAMA: Ministerio de Relaciones Exteriores, Panama.

PARAGUAY: Ministerio de Relaciones Exteriores, Sección Biblioteca, Asunción.

SALVADOR:

Biblioteca Nacional, San Salvador.

Ministerio de Relaciones Exteriores, San Salvador.

SCOTLAND: National Library of Scotland, Edinburgh.⁶

SIAM: National Library, Bangkok.

SINGAPORE: Chief Secretary, Government Offices, Singapore.

VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

There are now being sent abroad 83 copies of the Federal Register and 87 copies of the Congressional Record. This is an increase of 2 copies of the Federal Register and 12 of the Congressional Record over the preceding year. The countries to which these journals are being forwarded are given in the following list.

DEPOSITORIES OF CONGRESSIONAL RECORD AND FEDERAL REGISTER

ARGENTINA:

Biblioteca del Congreso Nacional, Buenos Aires.

Biblioteca del Poder Judicial, Mendoza.⁸

Cámara de Diputados, Oficina de Informacion Parlamentaria, Buenos Aires.

Boletín Oficial de la República Argentina, Ministerio de Justicia e Instrucción Pública, Buenos Aires.

AUSTRALIA:

Commonwealth Parliament and National Library, Canberra.

NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.

QUEENSLAND: Chief Secretary's Office, Brisbane.

WESTERN AUSTRALIA: Library of Parliament of Western Australia.

BRAZIL:

Biblioteca da Camera dos Deputados, Rio de Janeiro.

AMAZONAS: Archivo, Biblioteca e Imprensa Publica, Manáos.

BAHIA: Governador do Estado da Bahia, São Salvador.

ESPIRITO SANTO: Presidencia do Estado do Espirito Santo, Victoria.

⁸ Federal Register only.

BRAZIL—Continued

RIO GRANDE DO SUL: Imprensa Oficial do Estado, Porto Alegre.

SERGIPE: Biblioteca Publica do Estado de Sergipe, Aracajú.

SÃO PAULO: Imprensa Oficial do Estado, São Paulo.

BRITISH HONDURAS: Colonial Secretary, Belize.

CANADA:

Library of Parliament, Ottawa.

Clerk of the Senate, Houses of Parliament, Ottawa.

CUBA:

Biblioteca del Capitolio, Habana.

Biblioteca Publica Panamericana, Habana.⁸

House of Representatives, Habana.

CZECHOSLOVAKIA: Library of the Czechoslovak National Assembly, Prague.^{6 9}EGYPT: Ministry of Foreign Affairs, Egyptian Government, Cairo.⁹

EL SALVADOR: Library, National Assembly, San Salvador.

FRANCE:

Bibliothèque Assemblée Nationale, Paris.

Bibliothèque, Conseil de la République.

Library, Organization for European Economic Cooperation, Paris.^{6 9}Publiques de l'Institut de Droit Compare, Université de Paris, Paris.⁸Research Department, Council of Europe, Strasbourg.^{6 9}Service de la Documentation Étrangère, Assemblée Nationale, Paris.⁹GERMANY: Der Bayrische Landtag, Munich.^{9 10}Deutscher Bundesrat, Bonn.^{6 9}Deutscher Bundestag, Bonn.^{6 9}

GREAT BRITAIN:

House of Commons Library, London.⁹

Printed Library of the Foreign Office, London.

GREECE: Bibliothèque, Chambre des Députés Hellénique, Athens.¹¹

GUATEMALA: Biblioteca de la Asamblea Legislativa, Guatemala.

HAITI: Bibliothèque Nationale, Port-au-Prince.

HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.

INDIA:

Civil Secretariat Library, Lucknow, United Provinces.⁸Indian Council of World Affairs, New Delhi.^{6 9}

Legislative Assembly Library, Lucknow, United Provinces.

Legislative Department, Simla.

Parliament Library, New Delhi.^{6 9}

INDONESIA: Provisional Parliament of East-Indonesia, Macassar, Celebes.

IRELAND: Dail Eireann, Dublin.

ITALY:

Biblioteca Camera dei Deputati, Rome.

Biblioteca del Senato della Repubblica, Rome.

European Office, Food and Agriculture Organization of the United Nations, Rome.⁸International Institute for the Unification of Private Law, Rome.⁸⁹ Congressional Record only.¹⁰ Three copies.¹¹ Changed from Library, Greek Parliament.

JAPAN: Library of the National Diet, Tokyo.⁸

MEXICO:

Dirección General de Información, Secretaría de Gobernación, Mexico, D. F.
Biblioteca Benjamin Franklin, Mexico, D. F.

AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.

CAMPECHE: Gobernador del Estado de Campeche, Campeche.

CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.

CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.

COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.

COLIMA: Gobernador del Estado de Colima, Colima.

DURANGO: Gobernador Constitucional del Estado de Durango, Durango.

GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.

GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.

JALISCO: Biblioteca del Estado, Guadalajara.

LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali.

MÉXICO: Gaceta del Gobierno, Toluca.

MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.

MORELOS: Palacio de Gobierno, Cuernavaca.

NAYARIT: Gobernador de Nayarit, Tepic.

NUEVO LEÓN: Biblioteca del Estado, Monterrey.

OAXACA: Periódico Oficial, Palacia de Gobierno, Oaxaca.

PUEBLA: Secretaría General de Gobierno, Puebla.

QUERÉTARO: Secretaría General de Gobierno, Sección de Archivo, Querétaro.

SAN LUIS POTOSÍ: Congreso del Estado, San Luis Potosí.

SINALOA: Gobernador del Estado de Sinaloa, Culiacán.

SONORA: Gobernador del Estado de Sonora, Hermosillo.

TABASCO: Secretaría de Gobierno, Sesión 3a, Ramo de Prensa, Villahermosa.

TAMAULIPAS: Secretaría General de Gobierno, Victoria.

TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.

VERACRUZ: Gobernador del Estado de Veracruz, Departamento de Gobernación y Justicia, Jalapa.

YUCATÁN: Gobernador del Estado de Yucatán, Mérida.

NETHERLANDS: Koninklijke Bibliotheek, The Hague.⁸

NEW ZEALAND: General Assembly Library, Wellington.

NORWAY: Library of the Norwegian Parliament, Oslo.

PAKISTAN: Punjab Legislative Assembly, Lahore.⁶

PERU: Cámara de Diputados, Lima.

POLAND: Ministry of Justice, Warsaw.⁸

PORTUGAL: Secretaria da Assembla National, Lisbon.^{6 9}

SWITZERLAND: Bibliothèque, Bureau International du Travail, Geneva.⁸

Library, United Nations, Geneva.

International Labor Office, Geneva.^{8 12}

UNION OF SOUTH AFRICA:

CAPE OF GOOD HOPE: Library of Parliament, Cape Town.

TRANSVAAL: State Library, Pretoria.

UNION OF SOVIET SOCIALIST REPUBLICS: Fundamental'niia Biblioteka, Obshchestvennykh Nauk, Moscow.^{6 9}

¹² Two copies.

URUGUAY: Diario Oficial, Calle Florida 1178, Montevideo.

VENEZUELA: Biblioteca del Congreso, Caracas.

FOREIGN EXCHANGE AGENCIES

Exchange publications are forwarded to all countries except China and Rumania. The countries listed are those to which shipments are forwarded by freight. Packages of publications are forwarded to addresses in other countries directly by mail.

LIST OF AGENCIES

AUSTRIA: Austrian National Library, Vienna.

BELGIUM: Service des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.

CHINA: Bureau of International Exchange, National Central Library, Nanking.¹³

CZECHOSLOVAKIA: Bureau of International Exchanges, National and University Library, Prague.¹⁴

DENMARK: Institut des Échanges Internationaux, Bibliothèque Royale, Copenhagen K.

EGYPT: Government Press, Publications Office, Bulaq, Cairo.

FINLAND: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsinki.

FRANCE: Service des Échanges Internationaux, Bibliothèque Nationale, 58 Rue de Richelieu, Paris.

GERMANY: Öffentliche Wissenschaftliche Bibliothek, Berlin.^{15 16}

German Central Committee for Distribution of Cultural Materials, Stuttgart.^{15 17}

GREAT BRITAIN AND IRELAND: Wheldon & Wesley, 83/84 Berwick Street, London, W. 1.

HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.

INDIA: Superintendent of Government Printing and Stationery, Bombay.

ITALY: Ufficio degli Scambi Internazionali, Ministero della Pubblica Istruzione, Rome.

JAPAN: International Exchange Service, National Diet Library, Tokyo.¹⁸

NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

NEW ZEALAND: General Assembly Library, Wellington.

NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.

PALESTINE: Jewish National and University Library, Jerusalem.

PHILIPPINES: Bureau of Public Libraries, Department of Education, Manila.

POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.

PORTUGAL: Secção de Trocas Internacionais, Biblioteca Nacional, Lisbon.

¹³ Shipments suspended.

¹⁴ Changed from Bureau des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale.

¹⁵ Distribution under the supervision of the United States High Commissioner for Germany.

¹⁶ For all sectors of Berlin and the Eastern Zone.

¹⁷ For the Western Zone.

¹⁸ Changed from International Exchange Service, National Library of Japan.

QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.

RUMANIA: Ministère de la Propagande Nationale, Service des Échanges Internationaux, Bucharest.¹³

SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.

SPAIN: Junta de Intercambio y Adquisición de Libros y Revistas para Bibliotecas Públicas, Ministerio de Educación Nacional, Avenida Calvo Sotelo 20, Madrid.

SWEDEN: Kungliga Biblioteket, Stockholm.

SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Palais Fédérale, Berne.

TASMANIA: Secretary to the Premier, Hobart.

TURKEY: Ministry of Education, Department of Printing and Engraving, Istanbul.

UNION OF SOUTH AFRICA: Government Printing and Stationery Office, Cape Town, Cape of Good Hope.

UNION OF SOVIET SOCIALIST REPUBLICS: Bureau of Book Exchange, State Lenin Library, Moscow 19.¹⁹

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

YUGOSLAVIA: Federal Bibliographical Institute of Yugoslavia, Belgrade.²⁰

Respectfully submitted.

D. G. WILLIAMS, *Chief.*

Dr. A. WETMORE,

Secretary, Smithsonian Institution.

¹⁹ Changed from International Book Exchange Department, Society for Cultural Relations with Foreign Countries, Moscow 56.

²⁰ Changed from Section des Échanges Internationaux, Ministère des Affaires Étrangères.

APPENDIX 7

REPORT ON THE NATIONAL ZOOLOGICAL PARK

SIR: Transmitted herewith is a report on the operations of the National Zoological Park for the fiscal year ended June 30, 1950.

The value of the collection was enhanced by the acquisition of specimens that have not hitherto been on exhibition or that are rarities. As the Zoo is a combined educational, recreational, and research institution, the addition of new kinds of animals is of marked benefit. At the close of the year the personnel had been recruited to almost its authorized strength, and the rate of personnel turn-over had declined. Such good progress had been made in repair work that the general condition is definitely better than it has been for several years.

The National Zoological Park continues to do its utmost to further the expressed purpose of the Smithsonian Institution, "the increase and diffusion of knowledge among men," by constantly rendering a wide variety of services in addition to maintaining the exhibits. Valuable opportunities for research are afforded students of biology, particularly vertebrate zoology, as well as artists, photographers, and writers, utilizing only methods of study that do not endanger the welfare of the animals or of the public. Other services are answering in person, and by phone, mail, and telegraph, questions regarding animals and their care and transportation; furnishing information to other zoos and private and public agencies regarding structures for keeping and housing animals; cooperation with other agencies of the Federal, State, and municipal governments in research work; and preparation of articles for publication.

THE EXHIBITS

Specimens for exhibition are acquired by gift, deposit, purchase, exchange, births, and hatchings and are removed by death, exchange, or return of those on deposit. Although depositors are at liberty to remove their specimens, many leave them permanently.

As in any colony of living things, there is a steady turn-over, and so the exhibits are constantly changing. Thus, the inventory list of specimens in the collection on June 30 of each year does not show all the kinds of animals that were exhibited during the year; sometimes

creatures of outstanding interest at the time they were shown are no longer in the collection at the time the list is prepared.

ACCESSIONS

GIFTS

Many valuable additions to the collections were made by gifts during the past year.

The Government of India, through Prime Minister Jawaharlal Nehru and the Embassy of India in Washington, presented a pair of baby elephants. These were captured in Mysore and sent from Bombay to the States with a young Indian mahout, Baba Jan, in charge. The Isthmian Steamship Co. furnished free transportation for the elephants and a return passage for Baba Jan. They were officially presented by Madam Vijayalakshmi Pandit, Ambassador to the United States from India, through Assistant Secretary of State George C. McGhee, in the presence of some 70,000 people. Ashok, named after an ancient Indian emperor known for his peaceful reign, was about a year old. Shanti, an Indian word meaning peace (and also a girl's name), was about 2 years old. They adapted themselves immediately to life at the Zoo and are two much-admired animals.

The U. S. National Park Service captured and sent three grizzly bears, which were especially desirable additions inasmuch as the Zoo has had none for many years. Grizzlies are now so scarce that they are highly prized, and the courtesy of the National Park Service in supplying them is much appreciated. These three were removed from Yellowstone Park because they threatened to become a menace to visitors; otherwise they would not have been disturbed.

A number of shipments were received from members of the Armed Forces who had been abroad; many of them came from Malaya, where they were collected by Maj. Robert Traub, of the Army Medical Department, Research and Graduate School. Outstanding among the rare and interesting creatures are two pencil-tailed tree mice, a species seldom seen in captivity.

Miss Alice Birney Robert, Washington, D. C., presented a great gray kangaroo that her father obtained while in Australia.

The American Veterans Association presented "Amvet," an unusually fine lion cub, which promises to become a splendid adult.

Roy Humbert, of Eustis, Fla., sent four giant anolis lizards from Cuba.

Capt. Hugh L. Keegan, of the United States Army Medical Corps, sent a number of Philippine species, including two elephant trunk snakes, a tangalunga, a Philippine palm civet, and a slender-tailed cloud rat (*Phloeomys cumingi*).

The U. S. Fish and Wildlife Service continued sending valuable animals, including a Steller's sea lion from St. Paul Island, Alaska.

J. D. Handman, of Nyasaland, Africa, in making shipments of animals ordered from him, has in each case put in one or two extra creatures as gifts. The specimens are from a region not well known zoologically, and so all are of special interest.

An American black bear, "Smoky," a cub that had been rescued from a forest fire in New Mexico, was presented by the U. S. Forest Service. The animal was flown to Washington in a Piper Cub airplane, through the courtesy of Mr. Piper, and presented in connection with the Forest Service's campaign to emphasize the necessity for prevention and control of forest fires.

DEPOSITORS AND DONORS AND THEIR GIFTS

(Deposits are marked *)

Adams, Joseph L., Washington, D. C., opossum.
 Allen, Mrs. Arthur, Alexandria, Va., horned lizard.
 Allen, Robert F., Washington, D. C., 2 opossums.
 Allen, Ross, Ocala, Fla., 3 southern chicken snakes.
 AMVETS, Washington, D. C., lion cub.
 Anholt, R. W., Washington, D. C., Pekin duck.
 Aqueduct Police Force, Washington, D. C., water snake.
 Army Medical Department, Research and Graduate School, through Maj. Robert Traub, Washington, D. C., 2 pencil-tailed tree mice.
 Asbury, George, Jr., Washington, D. C., alligator.
 Austin, Arthur E., Washington, D. C., 2 rabbits, guinea pig.
 Baird, James, Triangle, Va., copperhead snake.
 Baldwin, Lt. Col. Charles, Canal Zone, 2 kinkajous.
 Barbour, Mrs., Sunnybrook, Md., Muscovy duck.
 Beckett, Howard, Lanham, Md., great horned owl.
 Bergen, R. P., Washington, D. C., Pekin duck.
 Bittenbender, C. R., Arlington, Va., Pekin duck.
 Blair, Mrs. Marge, Washington, D. C., Pekin duck.
 Blair, William, Hillwood Square, Va., horned grebe.
 Blocker, E. M., Fresno, Calif., California spotted skunk, 2 coyotes.
 Boatright, Miss Susie, Peacock, Tex., 4 horned lizards.
 Bockman, Chas. C., Baltimore, Md., blue goose.
 Boykin, Masters Robert and Richard, Washington, D. C., jumping mouse.
 Brill, Delbert, Washington, D. C., opossum.
 Brucker, Brad, Washington, D. C., black-widow spider.
 Buell, Miner W. and James, Bethesda, Md., 5 rabbits.
 Busbey, Bill, Berwyn, Md., 2 pygmy rattlesnakes, diamondback rattlesnake, black racer, opossum.
 Butler, C. P., Washington, D. C., 12 hermit crabs.
 Butler, William J., Chevy Chase, Md., opossum.
 Canada, Dr. R. O., Arlington, Va., 2 cottontail rabbits.
 Chaffe, Melvin, Washington, D. C., horned lizard.
 Charles, R. W., Washington, D. C., alligator.
 Cleveland Zoological Park, Cleveland, Ohio, 2 spur-winged geese.

Cliff, Arthur E., Washington, D. C., Pekin duck.
 Cline, L. A., Washington, D. C., chain king snake.
 Coleman, Mrs. Howard, Arlington, Va., 2 Pekin ducks.
 Collins, Mrs. J., Washington, D. C., horned lizard.
 Collins, Miss Jeanne, Washington, D. C., 7 rabbits.
 Comley, Clifford, Jr., Arlington, Va., 2 Pekin ducks.
 Costello, Mrs. E., Washington, D. C., Philippine macaque.
 Cottam, Dr. Clarence, Washington, D. C., white-fronted goose.
 Counts, R. L., Washington, D. C., rabbit.
 Darison, Mrs. G. F., Washington, D. C., albino gray squirrel.
 Davidson, Miss Mary, Washington, D. C., screech owl.
 Davis, Miss Elizabeth, Washington, D. C., 4 blue jays.
 Davis, Mrs. Elwood, Washington, D. C., rabbit.
 Davis, John, Washington, D. C., great blue heron.
 Davis, Malcolm, Calcutta, India, 2 koels.
 Dean, Mr., Sunnyside, Md., 70 bantam chickens.
 Denletian, Gary A., Washington, D. C., eastern nighthawk.
 Dickey, Donald, Suitland, Md., osprey.
 Dix, Mr. and Mrs. E. S., Vienna, Va., bobwhite quail.
 Doerr, William C., Washington, D. C., alligator.
 Dornin, W., Phoenix, Ariz., Boyle's king snake, 5 sidewinder rattlesnakes.
 Douglas, J. E., Rockville, Md., pilot black snake.
 DuFour, Mrs. E., Prince Georges County, Md., red, blue, and yellow macaw.
 Easterman, W. B., Arlington, Va., 2 Pekin ducks.
 Eleazer, J. M., Clemson, S. C., red-tailed hawk.
 Faul, Mrs. Henry, Lanham, Md., 4 opossums.
 Faust, John H., Washington, D. C., spotted salamander.
 Fickel, Miss Susan, Alexandria, Va., domestic rabbit.
 Fieser, Jimmy and Johnny, Bethesda, Md., Pekin duck.
 Fox, James B., Washington, D. C., goshawk.*
 French, Mrs. Patterson, Washington, D. C., baby alligator.
 Frey, Miss Jane, Washington, Pekin duck.
 Gabriel, Master Richard, Arlington, Va., Pekin duck.
 Garrett, Miss Betty I., Arlington, Va., alligator.
 Gassage, F. T., Takoma Park, Md., horned lizard.
 Gaver, Gordon, Thurmont, Md., king cobra,* 3 Indian cobras,* cape cobra,*
 boa constrictor,* central American boa,* rainbow boa,* regal python,* Indian
 rock python,* 3 Mexican tropical moccasins,* cottonmouth moccasin,* 3
 copperhead snakes,* chicken snake,* corn snake,* pine snake,* 2 black tegus,*
 Gila monster,* 4 rhesus monkeys,* 2 Javan macaques,* African monitor,*
 2 gila monsters,* 3 beaded lizards.*
 Gaynor, Donald B., Silver Spring, Md., 3 Pekin ducks.
 Geuton, John, McLean, Va., 4 Pekin ducks.*
 Gillespie, Mrs. Wm. V., Takoma Park, Md., ring-necked dove.
 Good, C. B., Gore, Va., raccoon.
 Gooden, Mrs. E. L., Takoma Park, Md., Pekin duck.
 Gouleit, Misses Gloria and Joann, Washington, D. C., 2 rabbits.
 Graham, Mrs. Wallace H., Washington, D. C., ocelot.
 Gray, Ralph, Arlington, Va., 2 gray raccoons.
 Green, Robert, Washington, D. C., barn owl.
 Greeson, L. E., Arlington, Va., fox squirrel.
 Griffin, Fred, Washington, D. C., black duck.
 Haggard, J. W., Washington, D. C., 5 hamsters.

- Haggerty, Miss Irene, Washington, D. C., 3 guinea pigs.
Hall, Miss Suzanne, Westgate, Md., Pekin duck.
Hamilton, A. G., Washington, D. C., mockingbird.
Handley, Charles, Washington, D. C., 3 guinea pigs, 12 hamsters.
Hanley, C., Arlington, Va., angora goat.
Hardy, Mrs. W. E., Bowie, Md., 2 wood ducks.
Harris, Mrs. E. G., Arlington, Va., 2 hamsters.
Harris, Lester E., Jr., Takoma Park, Md., pilot black snake.
Hassett, William D., The White House, mynah.*
Hayes, Buster, Tampa, Fla., Indian rock python,* coatiundi.*
Hebert, Emmett, A., Bethesda, Md., 2 Pekin ducks.
Hegener Research Supply, Sarasota, Fla., corn snake.
Heller, Miss Barbara, Washington, D. C., Pekin duck.
Hersfield, Master Peter, Alexandria, Va., raccoon.
Hicks, Robert, Washington, D. C., puma.*
Hoffman, R. A., Washington, D. C., double yellow-headed parrot.
Holcomb, V., Washington, D. C. blue heron.
Hook, Rev. Walter C., Fairfax, Va., 2 Pekin ducks.
Houser, Adam, Avondale, Md., 2 Pekin ducks.
Hughes, Chas., Silver Spring, Md., 4 fence lizards, 5 garter snakes, prairie rattlesnake, bull snake.
Hughes, Miss Gene, Washington, D. C., 2 red-shouldered hawks.
Humbert, Roy, Eustis, Fla., 4 giant anolis.
Hynes, Dr. Wm. P., Washington, D. C., 3 grass parakeets.
Indian Government, through Premier Jawaharlal Nehru, 2 Asiatic elephants.
Ingalls, Tommy, Washington, D. C., 2 white mice, 2 canaries.
Ingham, Rex, Ruffin, N. C., patas monkey,* rhesus monkey,* DeBrazza's guenon monkey,* sooty mangabey monkey,* great gray kangaroo,* scarlet snake.*
Jenkins, R. S., Buena Vista, Va., Philippine macaque.*
Johnson, Miss Betty, Chevy Chase, Md., raccoon.
Jolley, Edward M., Jr., Washington, D. C., black snake, copperhead.
Jones, Miss Marie, Washington, D. C., 2 white rabbits.
Judd, Master Robert, Chevy Chase, Md., flying squirrel.
Kahlaugh, Mrs. R., Knoxville, Tenn., sparrow hawk.
Kane, Miss Kathleen, Washington, D. C., Pekin duck.
Kaplin, Mrs. S., Takoma Park, Md., wood thrush.
Kaye, Joseph, Washington, D. C., 2 Pekin ducks, 2 rabbits.
Keegan, Capt. Hugh L., Pampanga, P. I., 2 elephant trunk snakes, tangalunga, Philippine palm civet, slender-tailed cloud rat.
Keller, Stanley, Silver Spring, Md., 2 crows.
Kelly, John S., Hyattsville, Md., 2 skunks.
Kemp, Mr., Washington, D. C., bobwhite quail.
Kidda, Mrs. Leonard, Washington, D. C., skunk.
Kincannon, Oliver, Chevy Chase, Md., 4 fighting fowl.
Kinsey, M. E., Washington, D. C., 2 rabbits.
Kintz, Maj. J. S., Washington, D. C., snapping turtle.
Knauss, Misses Sylvia and Miriam, McLean, Va., alligator.
Knight, Mrs. R. L., Silver Spring, Md., crow.
Kochanaki, Mr. and Mrs. J. F., Arlington, Va., 8 horned lizards.
Kreitzer, H. M., Silver Spring, Md., 2 Pekin ducks.
Kyriages, Gus, Alexandria, Va., loggerhead turtle.
Lamon, John C., Knoxville, Tenn., grass snake.
Lawburt, Max H., Washington, D. C., white rabbit.

Lawner, Mr., Chevy Chase, Md., hamster.
 Long, Lewis E., Washington, D. C., South American opossum and 4 young.
 Loraman, Mrs., Washington, D. C., red fox.
 Lund, Hugh, Arlington, Va., 2 Pekin ducks.
 MacBurnett, Mrs. R. D., Washington, D. C., horned lizard.
 Mackintosh, Master Dick, Bethesda, Md., water snake.
 Martin, Miss Diana, Washington, D. C., Pekin duck.
 Marx, Joy, Washington, D. C., gray squirrel.
 McCabe, John H., Arlington, Va., snowy owl.*
 McChaney, H. M., McLean, Va., mole snake.
 McCoy, Mrs. W. L., Kensington, Md., 4 Pekin ducks.
 McCrary, J. A., Washington, D. C., rabbit.
 McDowell, A. W. K., Annapolis, Md., great horned owl.
 McGill, Paul P., Arlington, Va., mockingbird.*
 McGraham, A., Washington, D. C., 2 opossums.
 McKnett, Mrs. John W., Washington, D. C., 4 mallard ducks.
 Meate, Mrs. May, Arlington, Va., Pekin duck.
 Meible, Mrs. John C., Washington, D. C., canary.*
 Miller, Miss B., Washington, D. C., Pekin duck.
 Miller, Roy, Washington, D. C., horned lizard.
 Millon, Arthur, Washington, D. C., 2 horned lizards.
 Mitchell, Master George, Arlington, Va., alligator.
 Montedonico, Joe, Bethesda, Md., garter snake, grass snake.
 Morgan, Joseph P., Baltimore, Md., 200 clawed frogs.*
 Morris, Dr. Anthony, Washington, D. C., 2 kangaroo rats.
 Morse, Thatcher, Washington, D. C., pilot black snake.
 Nash, Mrs. James T., Washington, D. C., capuchin monkey.
 Nelson, Helen May, Washington, D. C., baby alligator.
 Norris, A. N., Chevy Chase, Md., 2 albino-gray squirrels.
 O'Neill, Mrs. Wm. C., Alexandria, Va., Java finch.
 Owen, Miss Susan, Arlington, Va., Pekin duck.
 Paine, Mrs. D. C., and McGovern, Miss Joan, Arlington, Va., angora rabbit.
 Pamply, William A., Silver Spring, Md., 2 Pekin ducks.
 Pararas, J. L., Washington, D. C., alligator.
 Parkinson, Mrs. W. C., Washington, D. C., 100 guppies.
 Pates, W. W., Fredericksburg, Va., 2 red-shouldered hawks.
 Patterson, Mrs. H. French, Washington, D. C., baby alligator.
 Paul, Seymour, Balboa Heights, C. Z., coatimundi.*
 Perrott, Mr. and Mrs. Thomas A., North Arlington, Va., 4 Cumberland turtles.
 Pettis, Louis, and Miller, Jack, Washington, D. C., 4 barn owls.
 Pickett, Miss Evelyn, Washington, D. C., 2 Pekin ducks.
 Picot, Mrs. Hanison, Alexandria, Va., opossum.
 Preston, J. H., Mount Pleasant, Pa., 2 silver foxes, 2 platinum foxes.
 Pritchard, Hunter, Washington, D. C., hamster.
 Rabillard, Capt. and Mrs. G. N., Washington, D. C., domestic rabbit.
 Randel, Capt. Hugh W., Canal Zone, crested guan.
 Reese, Miss Barbara Ann, Alexandria, Va., 4 Pekin ducks.
 Ridder, Mrs. I. D., Clifton Forge, Va., 2 Philippine macaques.
 Roane, Wayne, Arlington, Va., hamster.
 Robert, Miss Alice Birney, Washington, D. C., great gray kangaroo.
 Robertson, Alaric Alvis, Arlington, Va., Pekin duck.
 Rose, Mrs. Joseph, Falmouth, Va., hamadryas baboon.

- Ryan, Thomas W., Washington, D. C., Canada goose.
 Sapp, Mary Ellen, Vincent, and Chris, Bethesda, Md., snapping turtle.
 Sargent, Mrs. V. W., Garrett Park, Md., coot.
 Sartain, W., Washington, D. C., sparrow hawk.
 Schwartz, Mrs. H., Washington, D. C., Pekin duck.
 Scott, Allwood, Washington, D. C., white rabbit.
 Scott, Joseph R., Arlington, Va., ring-necked pheasant.
 Seay, Mrs. Thomas, Washington, D. C., muskrat.
 Seielestad, H. D., Washington, D. C., copperhead.
 Sergeant, Russell, Washington, D. C., small alligator.
 Shaddix, W. N., Washington, D. C., barred owl.
 Sharpe, Miss Barbara A., Takoma Park, Md., white rabbit.
 Shaw, B., Washington, D. C., 2 ring-necked pheasants.
 Shaw, Brackley, Washington, D. C., 2 Pekin ducks.
 Silberman, James M., Washington, D. C., 2 spice finches, black-hooded red siskin.
 Simpson, Murry S., Chevy Chase, Md., skunk.
 Sinclair, L. A., Alexandria, Va., ring-necked pheasant.
 Sinclair, M. E., Herndon, Va., great horned owl.
 Smith, H. W., Washington, D. C., rabbit.
 Smith, Miss Hilda E., Silver Spring, Md., barn owl.
 Snapp, Mrs. Edwin C., Washington, D. C., Polyphemus moth.
 Snyder, Mrs. E. T., Washington, D. C., Pekin duck.
 Spicer, Master Curt J., Greenbelt, Md., 6 hamsters.
 Spicer, Jack, Arlington, Va., mink.
 Stevens, R. E., Washington, D. C., pilot black snake.
 Stover, Mrs. Harry B., Arlington, Va., crow.*
 Stover, Miss Susan, Chevy Chase, Md., opossum.
 Swift, C. B., Jr., Washington, D. C., Pekin duck.
 Tanit-Ikao, Princess, Lynbrook, N. Y., 3 Indian rock pythons,* alligator.
 Tapley, Mrs., Arlington, Va., chicken.
 Thompson, H. O., Brandon, Va., 2 Virginia deer.
 Thompson, W. E., Bethesda, Md., 12 Pekin ducks.
 Thompson School, Washington, D. C., rabbit.
 Thornton, Herbert, Washington, D. C., scarlet tanager.
 Trefflich's Bird & Animal Co., New York City, 2 great gray kangaroos.*
 Tullock, W. J., Jr., Alexandria, Va., alligator.
 U. S. Fish and Wildlife Service:
 Through Edward K. Beebe, Missoula, Mont., 2 pumas.
 Through Leon D. Cool, Rockville, Md., cardinal.
 Through Vernon Ekedahl, Sacramento National Wildlife Refuge, Willows, Calif., 2 snow geese, 4 cackling geese.
 Through K. F. Roahen, Billings, Mont., whistling swan.
 Through J. C. Savage, Klamath Falls, Oreg., 4 cackling geese.
 Through Dr. Victor Scheffer, St. Paul Island, Alaska, Steller's sea lion.
 U. S. Forest Service, New Mexico, through Homer C. Pickens, black bear cub.
 U. S. National Park Service, Washington, D. C., whistling swan.
 U. S. National Park Service, through Edmund B. Rogers, Yellowstone National Park, Wyo., 3 grizzly bears.
 Vaughn, Mrs. Harry H., Alexandria, Va., yellow-headed parrot.*
 Veckey, Mrs. L., Washington, D. C., ovenbird.

Vieth, Miss Elsie Jane, Washington, D. C., 2 Pekin ducks.
 Vinogradoff, Mrs. Gene, Alexandria, Va., 3 ring-necked doves.*
 Walters, H. R., Washington, D. C., 2 Pekin ducks.
 Warner, Tony, Washington, D. C., guinea pig.
 Washington Animal Rescue League, Washington, D. C., silver fox.
 Wayne, Mr. and Mrs. Robert, Washington, D. C., cheetah.*
 Weaver, W. C., Washington, D. C., saw-whet owl.
 Weisbender, Eugene R., Arlington, Va., 2 raccoons.
 Welch, Mr. (address unknown), coatimundi.
 Westbrook School, Washington, D. C., white rabbit.
 Wharton, Charles, Avondale Estates, Ga., 4 Cercomys, 1 Euryzgomatomys,
 cottonmouth moccasin, diamondback rattlesnake, copperhead snake, king
 snake, garter snake.
 White, Mrs. Harry D., Washington, D. C., Florida gallinule.
 Whitmore, Miss Catherine, Arlington, Va., rabbit.
 Wildrick, Mrs. Warren, Washington, D. C., weasel.*
 Williams, C. E., Washington, D. C., woolly monkey.*
 Williams, Mrs. M. C., Arlington, Va., sparrow hawk.
 Wills, Carl, Arlington, Va., skunk.
 Wise, Mrs. E. B., Washington, D. C., 3 guinea pigs.
 Wolf, Miss Mary, Washington, D. C., diamondback turtle.
 Wright, Albert, Arlington, Va., 2 Pekin ducks.
 Wyatt, Mrs. Walter, Washington, D. C., brown thrasher.
 Xidon, Mrs. Y., Washington, D. C., rabbit, frogs, salamanders.
 Zaroff, Mrs. J., Washington, D. C., cooter turtle.
 Zoological Society of Philadelphia, 2 red wolves, 3 coyotes.

PURCHASES

Some of the more important of the year's purchases include a pair each of great-eared foxes and fennecs; two echidnas which have been continuously on exhibition for more than a year; a pair of Steller's sea lions; a pair of red howler monkeys; a greater bird of paradise; a pair of Siberian red-breasted geese; and a male armadillo.

BIRTHS AND HATCHINGS

It was a surprise when both pairs of the Zoo's hybrid bears (female Alaska brown bear \times male polar bear) produced litters of cubs. One of the cubs (named Gene) was raised and has grown into a husky bear and, because of its ancestry, a famous one.

The English Park cattle, the gaur, the pygmy hippopotami, and the Chinese water deer have been breeding regularly.

A baby black-fronted duiker was born.

One pair of Acoumba lemurs produced a young one that has done amazingly well.

A pair of snowy egrets in the flight cage at the bird house built a nest, hatched two eggs, and raised the young to maturity.

Roseate spoonbills nested and hatched three young.

MAMMALS

Scientific name	Common name	Number
<i>Ammotragus lervia</i>	Aoudad.....	9
<i>Axis axis</i>	Axis deer.....	1
<i>Bos taurus</i>	English Park cattle.....	2
<i>Bibos gaurus</i>	Gaur.....	1
<i>Cephalophus nigrifrons</i>	Black-fronted duiker.....	1
<i>Cercopithecus aethiops sabaeus</i> × <i>C. a.</i> <i>pygerythrus</i>	Green guenon × vervet guenon.....	1
<i>Cercopithecus diana</i>	Diana monkey.....	1
<i>Cervus nippon</i>	Japanese deer.....	1
<i>Choeropsus liberiensis</i>	Pygmy hippopotamus.....	2
<i>Cuniculus paca</i>	Paca.....	1
<i>Dama dama</i>	{ Brown fallow deer.....	7
	{ White fallow deer.....	5
<i>Felis concolor</i> × <i>F. c. patagonica</i>	Puma.....	3
<i>Hippopotamus amphibius</i>	Hippopotamus.....	1
<i>Hydropotes inermis</i>	Chinese water deer.....	4
<i>Hylobates agilis</i> × <i>H. lar pilcatus</i>	Hybrid gibbon.....	1
<i>Leontocebus rosalia</i>	Lion-headed marmoset.....	2
<i>Mephitis mephitis nigra</i>	Skunk.....	6
<i>Otocyon megalotis</i>	Great-eared fox.....	3
<i>Tamandua tetradactyla</i>	Tamandua anteater.....	1
<i>Taurotragus oryx</i>	Eland.....	1
<i>Thalarcos maritimus</i> × <i>Ursus middend-</i> <i>dorffi</i> (2d generation, 2 litters of 3 each)	Hybrid bear.....	6

BIRDS

<i>Ajaia ajaja</i>	Roseate spoonbill.....	3
<i>Chenopsis atrata</i>	Black swan.....	4
<i>Haliaeetus leucocephalus</i>	Bald eagle.....	1
<i>Leucophoyx thula</i>	Snowy heron.....	2
<i>Streptopelia tranquebarica</i>	Blue-headed ring dove.....	7

REPTILES

<i>Crotalus terrificus</i>	Mexican rattlesnake.....	14
<i>Constrictor constrictor</i>	Boa constrictor.....	32

RESEARCH

Scientific research is not set up as a separate activity in the National Zoological Park but is an important part of the operation. The proper care of hundreds of different kinds of animals, some of which have not previously been kept alive, calls for constant observation and study to determine for each one its natural living conditions, likes and dislikes. Usually the most important step is to try foods that will be acceptable substitutes for those that the animals would normally obtain in the wild. Other conditions, such as humidity, temperature, type of bedding, types of perch, indeed everything affecting

the animal in captivity, require constant study to make certain that a suitable environment is maintained. Failure to provide the proper conditions is likely to result in the loss of animals that are often of great value and are sometimes irreplaceable. Even if the animals do not die, they are almost certain to become unsuitable for exhibition if not properly cared for.

In the course of carrying on in his home studies of small mammals that were not well known or that had been considered difficult or impossible to keep alive in captivity, the Assistant Director has developed a food mixture that has proved highly satisfactory. The lesser short-tailed shrew (*Cryptotis parva*) and the large African elephant shrew (*Macroscelides rufescens*) were fed this and produced young, the short-tailed shrews even producing the second generation in captivity. Four species of bats thrived on this diet exclusively. The greater short-tailed shrews (*Blarina brevicauda*) and star-nosed mole (*Condylura cristata*) preferred this to most other food. It has been offered to many other small and medium-sized mammals such as marmosets, night monkeys, and several different kinds of rodents and carnivores, practically all of which like the food. It has been so successful with specialized mammals that have heretofore been very difficult or impossible to keep in captivity, that it appears worth while to publish the formula:

One yolk of hard-boiled egg; approximately an equal amount of rather dry cottage cheese; approximately an equal amount of ripe banana; approximately an equal amount of mealworms; 6 drops of Jeculin; 6 drops of wheat-germ-oil; 6 grains of Theragram.

Make up the mixture with a mortar and pestle. If the wheat-germ oil is in 3-minim capsules put in two; add the Theragram, which is a yellowish paste; add a few drops of water to soften the gelatin of the wheat-germ-oil capsules and to dissolve the Theragram. Then put in the other ingredients and grind all together with the pestle until a paste is formed with the chitin of the mealworms scattered through it.

The mealworms (*Tenebrio molitor*) are the same as, or similar to, those that get into cereals. Cultures of them can be maintained in bran or cornmeal with the addition of banana peelings, slices of raw potato, and occasionally light sprinklings of water to moisten the bran or cornmeal very slightly but not enough to cause it to form lumps or to mildew.

The Assistant Director has also developed a milk mixture that has been tried out with many small mammals with excellent success. It is as follows:

Three ounces cow's milk from which about one-third of the cream has been removed; 1 teaspoonful raw egg yolk; 4 drops Jeculin; 1 drop Navitol or Viosterol; $\frac{1}{4}$ teaspoonful calcium gluconate.

Stir until thoroughly mixed. Keep in refrigerator. Warm the small amount needed for each feeding. Use same care in sterilizing utensils as would be used in caring for a human baby.

MAINTENANCE AND IMPROVEMENTS

In addition to the numerous daily small repairs, substantial progress was made during the year in maintenance work of a more permanent improvement character.

The 85,000-gallon sea-lion pool that had been leaking seriously was completely relined with concrete. Four-hundred linear feet of concrete coping for fence was built and 400 feet of 6-foot fencing erected thereon; a parking area between the restaurant and the creek, 300 feet long and 20 feet wide, was given a bituminous-stone surfacing; the surface of the area behind the cages above the reptile house was improved by 2,100 square feet of cement surfacing, 175 linear feet of curb, 175 feet of concrete retaining wall 4 feet high, and 60 linear feet of steps; V-gutters were installed in front of these cages. This will improve the appearance of the area, check erosion, and improve sanitation. Three hundred eighty-six feet of 4-inch soil pipe and fittings were installed to provide for sewage disposal from the vicinity of the cook house; a high-voltage cable was laid from the basement of the reptile house to the cook house to provide current for the electric oven. The space in the bird house formerly occupied by eight double-deck bird cages that had never been satisfactory was remodeled to accommodate three large cages that are much better. Five thousand square feet of parking area was surfaced with bituminous-stone mixture. At odd times, particularly when outside work could not be carried on, the making of cement legs for benches and cement tables was continued.

VISITORS

The number of visitors was 3,437,669, an increase of 91,619 over the previous year. This was the largest attendance in the history of the Zoo and was probably due in part to the continued high employment in the Washington area, increase in travel accompanying the general economic prosperity, and the frequency with which the Zoo was able to announce the addition of interesting specimens to the collection. The variation in attendance on the different days of the week, which was so extreme before the war, has been much less noticeable. Formerly early days of the week had relatively low attendance, with an increasing number of visitors the latter portion of the week, and very large crowds on Saturdays, Sundays, and holidays. There is also a considerable increase in the earlier hours of the day.

ESTIMATED NUMBER OF VISITORS FOR FISCAL YEAR 1950

July (1949).....	419, 000	February.....	133, 350
August.....	475, 700	March.....	208, 450
September.....	372, 200	April.....	447, 419
October.....	262, 200	May.....	406, 000
November.....	175, 400	June.....	288, 500
December.....	71, 350		
January (1950).....	178, 100	Total.....	3, 437, 669

Groups came to the Zoo from schools in 31 States, some as far away as Maine, Florida, Washington, California, and New Mexico. There was an increase of 129 groups and 8,901 individuals in groups over last year.

NUMBER OF GROUPS FROM SCHOOLS

	Number of groups	Number in groups		Number of groups	Number in groups
Alabama.....	9	256	New Hampshire.....	1	44
California.....	1	33	New Jersey.....	18	1,060
Connecticut.....	11	455	New Mexico.....	1	18
Delaware.....	17	731	New York.....	84	5,253
District of Columbia.....	135	7,070	North Carolina.....	199	6,720
Florida.....	3	556	Ohio.....	70	2,624
Georgia.....	48	2,850	Oklahoma.....	1	13
Illinois.....	2	39	Pennsylvania.....	243	11,580
Indiana.....	9	291	Rhode Island.....	1	38
Kentucky.....	7	252	South Carolina.....	58	1,825
Maine.....	12	696	South Dakota.....	1	80
Maryland.....	582	34,493	Tennessee.....	46	1,983
Massachusetts.....	13	1,215	Virginia.....	346	19,602
Michigan.....	15	545	Washington.....	1	36
Minnesota.....	1	42	West Virginia.....	35	1,942
Mississippi.....	2	138			
Missouri.....	1	50	Total.....	1,973	102,553

About 2 p.m. each day the cars then parked in the Zoo are counted by the Zoo police and listed according to the State, Territory, or country from which they came. This is, of course, not a census of the cars coming to the Zoo but is valuable in showing the percentage of attendance, by States, of people in private automobiles. The tabulation for the fiscal year 1950 is as follows:

	Percent		Percent
Maryland.....	26.0	Ohio.....	1.7
Washington, D. C.....	25.5	West Virginia.....	1.5
Virginia.....	20.9	New Jersey.....	1.3
Pennsylvania.....	4.4	Massachusetts.....	1.0
North Carolina.....	2.4	California.....	0.9
New York.....	2.3	Florida.....	0.8

The cars that made up the remaining 11.3 percent came from every one of the remaining States, as well as from Alaska, Bahamas, Belgium, Canada, Canal Zone, Cuba, Dutch West Indies, France, Guam, Guatemala, Hawaii, Japan, Mexico, Newfoundland, Okinawa, Philippines, Poland, Puerto Rico, and Saipan.

FINANCES

The regular appropriation provided in the District of Columbia appropriation act was \$544,700.

The stone restaurant building, which was constructed in the Park in 1940 under an allotment of \$90,000, is under a 3-year lease, obtained by competitive bidding, at \$23,052 per annum. This money is deposited in the general fund of the United States Treasury. The concessionaire serves meals and light refreshments and sells souvenirs.

NEEDS OF THE ZOO

The principal needs of the Zoo remain as they have for several years, i. e., the replacement of antiquated structures that have long since ceased to be suitable for the purpose. The more urgently needed buildings are: (1) A new administration building to replace the 145-year-old historic landmark now in use for an office building for the Zoo, but which is neither suitably located nor well adapted for the purpose. This building is in an excellent location for a public recreational structure and could probably be rehabilitated and used for recreational purposes, perhaps as a children's museum, and thus maintained as a historic building. The new office building should be better located both from the standpoint of accessibility to the public and convenience for the administration of the Zoo. (2) A new building to house antelopes and other medium-sized hoofed animals that require a heated building.

STATUS OF THE COLLECTION

Class	Species or sub- species	Individ- uals	Class	Species or sub- species	Individ- uals
Mammals.....	243	734	Insects.....	2	103
Birds.....	353	1,087	Mollusks.....	2	4
Reptiles.....	113	487			
Amphibians.....	29	148	Total.....	771	2,821
Fish.....	29	258			

SUMMARY

Animals on hand July 1, 1949.....	12,947
Accessions during the year.....	1,414
Total number of animals in collection during the year.....	4,361
Removals for various reasons such as death, exchanges, return of animals on deposit, etc.....	1,540
In collection on June 30, 1950.....	2,821

¹ The total 3,724 given in last year's report was in error.

ANIMALS IN THE COLLECTION, JUNE 30, 1950

MAMMALS

MONOTREMATA

Scientific name	Common name	Number
Tachyglossidae:		
<i>Tachyglossus aculeatus</i>	Echidna or spiny anteater.....	2

MARSUPIALIA

Didelphiidae:		
<i>Didelphis virginiana</i>	Opossum.....	5
<i>Metachirus nudicaudatus</i>	South American naked-tailed opossum	1
Phalangeridae:		
<i>Petaurus norfolcensis</i>	Australian flying phalanger....	2
<i>Trichosurus vulpecula</i>	Vulpine opossum.....	2
Macropodidae:		
<i>Dendrolagus inustus</i>	New Guinea tree kangaroo....	1

INSECTIVORA

Tupaiaidae:		
<i>Urogale everetti</i>	Philippine tree shrew.....	2
Macroscelididae:		
<i>Macroscelides rufescens</i>	East African elephant shrew....	3

PRIMATES

Lemuridae:		
<i>Lemur macaco</i>	Acoumba lemur.....	3
<i>Lemur mongoz</i>	Mongoose lemur.....	2
Lorisidae:		
<i>Nycticebus coucang</i>	Slow loris.....	2
Callithricidae:		
<i>Leontocebus rosalia</i>	Silky or lion-headed marmoset..	2
<i>Marikina oedipus</i>	Cotton-headed marmoset.....	1
<i>Oedipomidas geoffroyi</i>	Geoffroy's marmoset.....	13
Cebidae:		
<i>Alouatta seniculus</i>	Red howler monkey.....	2
<i>Aotus trivirgatus</i>	Douroucoulis or night monkey..	5
<i>Ateles geoffroyi vellerosus</i>	Spider monkey.....	2
<i>Cebus apella</i>	Gray capuchin.....	2
<i>Cebus capucinus</i>	White-throated capuchin.....	3
<i>Cebus fatuellus</i>	Weeping capuchin.....	2
<i>Pithecia pithecia</i>	Saki monkey.....	2
Cercopithecidae:		
<i>Cercocebus atterimus</i>	Black-crested mangabey.....	1
<i>Cercocebus fuliginosus</i>	Sooty mangabey.....	2
<i>Cercopithecus aethiops pygerythrus</i> ...	Vervet guenon.....	1
<i>Cercopithecus aethiops sabaeus</i>	Green guenon.....	8
<i>Cercopithecus aethiops sabaeus</i> × <i>C.</i> <i>a. pygerythrus</i>	Hybrid, green guenon × vervet guenon.....	3
<i>Cercopithecus cephus</i>	Moustached guenon.....	2
<i>Cercopithecus diana</i>	Diana monkey.....	3

Scientific name	Common name	Number
Cercopithecidae—Continued		
<i>Cercopithecus diana roloway</i>	Roloway monkey.....	1
<i>Cercopithecus neglectus</i>	De Brazza's guenon.....	1
<i>Cercopithecus nictitans petaurista</i>	Lesser white-nosed guenon.....	1
<i>Cercopithecus preussi</i>	Preussi's guenon.....	1
<i>Erythrocebus patas</i>	Patas monkey.....	2
<i>Gymnopyga maurus</i>	Moor monkey.....	1
<i>Macaca irus</i>	Crab-eating macaque.....	1
<i>Macaca irus mordax</i>	Javan macaque.....	5
<i>Macaca lasiotis</i>	Chinese macaque.....	1
<i>Macaca mulatta</i>	Rhesus monkey.....	15
<i>Macaca nemestrina</i>	Pig-tailed monkey.....	2
<i>Macaca philippinensis</i>	Philippine macaque.....	7
<i>Macaca silenus</i>	Wanderoo monkey.....	1
<i>Macaca sinica</i>	Toque or bonnet monkey.....	1
<i>Macaca speciosa</i>	Red-faced macaque.....	2
<i>Macaca sylvanus</i>	Barbary ape.....	4
<i>Mandrillus sphinx</i>	Mandrill.....	2
<i>Papio cynocephalus</i>	Golden baboon.....	1
<i>Papio hamadryas</i>	Hamadryas baboon.....	3
<i>Papio porcarius</i>	Chacma baboon.....	4
Hylobatidae:		
<i>Hylobates agilis</i>	Sumatran gibbon.....	1
<i>Hylobates agilis</i> × <i>H. lar pileatus</i>	Hybrid gibbon.....	1
<i>Hylobates hoolock</i>	Hoolock gibbon.....	1
<i>Hylobates lar pileatus</i>	Black-capped gibbon.....	1
Pongidae:		
<i>Pan satyrus</i>	Chimpanzee.....	2
<i>Pongo pygmaeus abelii</i>	Orangutan.....	2
EDENTATA		
Dasypodidae:		
<i>Chaetophractus villosus</i>	Hairy armadillo.....	1
<i>Euphractus sexcinctus</i>	Six-banded armadillo.....	1
Myrmecophagidae:		
<i>Myrmecophaga tridactyla</i>	Giant anteater.....	1
<i>Tamandua tetradactyla</i>	Three-toed anteater.....	2
LAGOMORPHA		
Leporidae:		
<i>Oryctolagus cuniculus</i>	Domestic rabbit.....	10
<i>Sylvilagus floridanus</i>	Cottontail rabbit.....	1
RODENTIA		
Sciuridae:		
<i>Callosciurus nigrovittatus</i>	Southern Asiatic squirrel.....	1
<i>Callosciurus prevostii</i>	Tricolored squirrel.....	1
<i>Callospermophilus lateralis</i>	Albino golden-mantled ground squirrel.....	1
<i>Citellus beecheyi douglasii</i>	Douglas's ground squirrel.....	2
<i>Cynomys ludovicianus</i>	Plains prairie dog.....	30

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Sciuridae—Continued		
<i>Eutamias speciosus</i>	San Bernardino chipmunk.....	1
<i>Glaucomys volans</i>	Flying squirrel.....	3
<i>Marmota monax</i>	Woodchuck or ground hog.....	4
<i>Sciurus carolinensis</i>	Gray squirrel.....	1
<i>Sciurus carolinensis</i>	Albino gray squirrel.....	2
<i>Sciurus niger</i>	Fox squirrel.....	1
<i>Tamias striatus</i>	Eastern chipmunk.....	2
<i>Tamiasciurus hudsonicus</i>	Red squirrel.....	1
Geomyidae:		
<i>Thomomys bottae mewa</i>	Pocket gopher.....	3
Heteromyidae:		
<i>Dipodomys microps</i>	Small-faced kangaroo rat.....	1
<i>Dipodomys spectabilis</i>	Large kangaroo rat.....	1
Cricetidae:		
<i>Gerbillus pyramidum</i>	Gerbil.....	3
<i>Meriones unguiculatus</i>	Mongolian gerbil.....	1
<i>Mesocricetus auratus</i>	Golden hamster.....	15
<i>Microtus californicus</i>	California meadow mouse.....	4
<i>Microtus pennsylvanicus</i>	Meadow mouse.....	1
<i>Neotoma lepida</i>	Pack rat.....	2
<i>Ondatra zibethicus</i>	Muskrat.....	2
<i>Peromyscus leucopus</i>	Eastern white-footed mouse.....	3
<i>Peromyscus maniculatus gambeli</i>	Gambel's white-footed mouse.....	13
<i>Peromyscus maniculatus sonoriensis</i>	Sonoran white-footed mouse.....	1
<i>Peromyscus n. nuttalli</i>	Northern golden mouse.....	1
<i>Reithrodontomys megalotis longicaudus</i>	California harvest mouse.....	3
<i>Tatera schinzi shirensis</i>	Nyasaland gerbil.....	7
Rhizomyidae:		
<i>Rhizomys sumatrensis</i>	Bay bamboo rat.....	2
Muridae:		
<i>Acomys cahirinus</i>	Egyptian spiny mouse.....	4
<i>Chiropodomys gliroides</i>	Pencil-tailed tree mouse.....	1
<i>Mus musculus</i>	White and other domestic mice.....	10
<i>Phloeomys cumingi</i>	Slender-tailed cloud rat.....	3
<i>Rattus bowersi</i>	Bower's tree rat.....	1
<i>Rattus cremoriventer</i>	Pencil-tailed tree rat.....	1
<i>Rattus edwardsi</i>	Edward's tree rat.....	2
<i>Rattus mülleri</i>	Müller's tree rat.....	2
<i>Rattus rajah</i>	Rajah tree rat.....	1
<i>Rattus rattus</i>	Hooded laboratory rat.....	5
<i>Rattus sabanus</i>	Large spiny-backed tree rat.....	2
<i>Rattus whiteheadi</i>	Whitehead's tree rat.....	1
<i>Saccostomus sp</i>	African pouched mouse.....	1
Zapodidae:		
<i>Zapus hudsonius</i>	Jumping mouse.....	1
Hystriidae:		
<i>Acanthion brachyurum</i>	Malay porcupine.....	3
<i>Atherurus africanus</i>	West African brush-tailed porcupine.....	1
<i>Hystrix galeata</i>	African porcupine.....	2

Scientific name	Common name	Number
Caviidae:		
<i>Cavia porcellus</i>	Guinea pig.....	10
<i>Dolichotis patagonica</i>	Patagonian cavy.....	3
Dasyproctidae:		
<i>Cuniculus paca</i>	Paca.....	4
<i>Dasyprocta prymnolopha</i>	Agouti.....	2
<i>Dasyprocta punctata</i>	Speckled agouti.....	2
Chinchillidae:		
<i>Chinchilla chinchilla</i>	Chinchilla.....	3
<i>Lagidium viscaccia</i>	Peruvian viscacha.....	3
Capromyidae:		
<i>Capromys pilorides</i>	Hutia.....	3
Myocastoridae:		
<i>Myocastor coypus</i>	Coypu.....	4
Abrocomidae:		
<i>Abrocoma bennetti</i>	Abrocoma.....	1
Echimyidae:		
<i>Cercomys cunicularius</i>	Cercomys.....	1
<i>Euryzgomatomys</i> sp.....	Euryzgomatomys.....	1
Thryonomyidae:		
<i>Thryonomys swinderianus</i>	Cane rat.....	1
Bathyergidae:		
<i>Cryptomys</i> sp.....	Mole-rat.....	4

CARNIVORA

Canidae:		
<i>Alopex lagopus</i>	Arctic fox.....	1
<i>Canis antarcticus</i>	Dingo.....	2
<i>Canis latrans</i>	Coyote.....	5
<i>Canis lupus nubilus</i>	Plains wolf.....	1
<i>Canis niger rufus</i>	Texas red wolf.....	2
<i>Fennecus zerda</i>	Fennec fox.....	2
<i>Nyctereutes procyonoides</i>	Raccoon dog.....	1
<i>Otocyon megalotis</i>	Big-eared fox.....	2
<i>Urocyon cinereoargenteus</i>	Gray fox.....	12
<i>Vulpes fulva</i>	Red fox.....	6
<i>Vulpes fulva</i>	Silver fox.....	5
Ursidae:		
<i>Euarctos americanus</i>	Black bear.....	4
<i>Euarctos thibetanus</i>	Himalayan bear.....	1
<i>Helarctos malayanus</i>	Malay or sun bear.....	1
<i>Melursus ursinus</i>	Sloth bear.....	1
<i>Thalarctos maritimus</i>	Polar bear.....	2
<i>Thalarctos maritimus</i> × <i>Ursus middendorffi</i>	Hybrid bear.....	¹ 5
<i>Tremarctos ornatus</i>	Spectacled bear.....	2
<i>Ursus arctos</i>	European brown bear.....	1
<i>Ursus arctos occidentalis</i>	Syrian brown bear.....	2
<i>Ursus gyas</i>	Alaskan Peninsula bear.....	2
<i>Ursus horribilis</i>	Grizzly bear.....	3
<i>Ursus middendorffi</i>	Kodiak bear.....	2
<i>Ursus sitkensis</i>	Sitka brown bear.....	3
<i>Ursus</i> sp.....	Alaska brown bear.....	1

First generation 4; second generation 1.

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Procyonidae:		
<i>Bassariscus astutus</i>	Ringtail or cacomistle.....	1
<i>Nasua narica</i>	Coatimundi.....	8
<i>Nasua nelsoni</i>	Nelson's coatimundi.....	1
<i>Potos flavus</i>	Kinkajou.....	6
<i>Potos</i> sp.....	Dwarf kinkajou.....	2
<i>Procyon lotor</i>	{ Raccoon.....	20
	{ Black raccoon.....	3
	{ Raccoon (albino).....	1
Mustelidae:		
<i>Lutra canadensis vaga</i>	Florida otter.....	1
<i>Martes flavigula henricii</i>	Asiatic marten.....	1
<i>Meles meles leptorhynchus</i>	Chinese badger.....	1
<i>Mephitis mephitis nigra</i>	Skunk.....	4
<i>Mustela eversmanni</i>	Ferret.....	1
<i>Mustela noveboracensis</i>	Weasel.....	1
<i>Mustela rixosa</i>	Least weasel.....	1
<i>Spilogale phenax</i>	California spotted skunk.....	1
<i>Taxidea taxus</i>	American badger.....	8
<i>Tayra barbara barbara</i>	White tayra.....	1
<i>Tayra barbara senilis</i>	Gray-headed tayra.....	1
Viverridae:		
<i>Civettictis civetta</i>	African civet.....	1
<i>Crossarchus obscurus</i>	Kusimanse.....	1
<i>Myonax sanguineus</i>	Dwarf civet.....	1
<i>Nandinia binolata</i>	African palm civet.....	1
<i>Paradoxurus hermaphroditus</i>	Small-toothed palm civet.....	3
<i>Paradoxurus philippinensis</i>	Philippine palm civet.....	1
<i>Viverra zangalunga</i>	Ground civet.....	1
Hyaenidae:		
<i>Crocuta crocuta germinans</i>	East African spotted hyena.....	2
Felidae:		
<i>Felis chaus</i>	Jungle cat.....	1
<i>Felis concolor</i>	Puma.....	4
<i>Felis concolor</i> × <i>F. c. patagonica</i>	Hybrid, North American puma × South American puma.....	6
<i>Felis leo</i>	Lion.....	5
<i>Felis onca</i>	Jaguar.....	3
<i>Felis pardalis</i>	Ocelot.....	2
<i>Felis pardus</i>	Black Indian leopard.....	1
<i>Felis pardus</i>	African leopard.....	2
<i>Felis temminckii</i>	Golden cat.....	1
<i>Felis tigris</i>	Bengal tiger.....	4
<i>Felis tigris sumatrae</i>	Sumatran tiger.....	2
<i>Oncifelis geoffroyi</i>	Geoffroy's cat.....	3
<i>Oncilla pardinaoides</i>	Lesser tiger cat.....	1

PINNIPEDIA			
Scientific name	Common name	Number	
Otariidae:			
<i>Eumetopias jubata</i>	Steller's sea lion.....	1	
Phocidae:			
<i>Phoca vitulina richardii</i>	Pacific harbor seal.....	1	
TUBULIDENTATA			
Orycteropodidae:			
<i>Orycteropus afer</i>	Aardvark or ant bear.....	1	
PROBOSCEIDA			
Elephantidae:			
<i>Elephas maximus</i>	Asiatic elephant.....	3	
<i>Loxodonta africana oxyotis</i>	African elephant.....	1	
HYRACOIDEA			
Procaviidae:			
<i>Procavia capensis</i>	Hyrax.....	2	
PERISSODACTYLA			
Equidae:			
<i>Equus burchellii antiquorum</i>	Chapman's zebra.....	1	
<i>Equus kiang</i>	Asiatic wild ass or kiang.....	1	
<i>Equus onager</i>	Onager.....	1	
<i>Equus przewalskii</i>	Mongolian wild horse.....	2	
<i>Equus quagga granti</i>	Grant zebra.....	2	
<i>Equus zebra</i>	Mountain zebra.....	1	
Rhinocerotidae:			
<i>Diceros bicornis</i>	Black rhinoceros.....	1	
<i>Rhinoceros unicornis</i>	Great Indian one-horned rhinoceros.....	1	
ARTIODACTYLA			
Suidae:			
<i>Babirusa babirusa</i>	Babirusa.....	1	
<i>Phacochoerus aethiopicus aeliani</i>	East African wart hog.....	2	
<i>Sus scrofa</i>	European wild boar.....	2	
Tayassuidae:			
<i>Pecari angulatus</i>	Collared peccary.....	1	
Hippopotamidae:			
<i>Choeropsis liberiensis</i>	Pygmy hippopotamus.....	9	
<i>Hippopotamus amphibius</i>	Hippopotamus.....	2	
Camelidae:			
<i>Camelus bactrianus</i>	Bactrian camel.....	3	
<i>Camelus dromedarius</i>	Single-humped camel.....	3	
<i>Lama glama</i>	Llama.....	1	
<i>Lama glama guanico</i>	Guanaco.....	3	
<i>Lama pacos</i>	Alpaca.....	3	
<i>Vicugna vicugna</i>	Vicuña.....	1	

	Scientific name	Common name	Number
Cervidae:			
	<i>Axis axis</i>	Axis deer.....	2
	<i>Cervus canadensis</i>	American elk.....	4
	<i>Cervus elaphus</i>	Red deer.....	1
	<i>Cervus nippon</i>	Japanese deer.....	4
	<i>Cervus nippon manchuricus</i>	Dybowsky's deer.....	2
	<i>Dama dama</i>	{ Fallow deer.....	16
		{ White fallow deer.....	20
	<i>Hydropotes inermis</i>	Chinese water deer.....	6
	<i>Odocoileus virginianus</i>	Virginia deer.....	5
Giraffidae:			
	<i>Giraffa camelopardalis</i>	Nubian giraffe.....	5
	<i>Giraffa reticulata</i>	Reticulated giraffe.....	1
Bovidae:			
	<i>Ammotragus lervia</i>	Aoudad.....	29
	<i>Bibos gaurus</i>	Gaur.....	5
	<i>Bison bison</i>	American bison.....	13
	<i>Bos indicus</i>	Zebu.....	3
	<i>Bos taurus</i>	Domestic cow (Jersey).....	1
	<i>Bos taurus</i>	West Highland or Kyloe cattle.....	4
	<i>Bos taurus</i>	British Park cattle.....	5
	<i>Bubalus bubalis</i>	Water buffalo.....	2
	<i>Capra sibirica</i>	Ibex.....	1
	<i>Cephalophus maxwellii</i>	Maxwell's duiker.....	1
	<i>Cephalophus nigrifrons</i>	Black-fronted duiker.....	3
	<i>Hemitragus jemlahicus</i>	Tahr.....	3
	<i>Limnotragus spekii</i>	Sitatunga.....	1
	<i>Oryx leucoryx</i>	Arabian oryx.....	1
	<i>Ovis aries</i>	Domestic sheep.....	1
	<i>Ovis europaea</i>	Mouflon.....	1
	<i>Poephagus grunniens</i>	Yak.....	4
	<i>Pseudois nayaur</i>	Bharal or blue sheep.....	1
	<i>Syncerus caffer</i>	African buffalo.....	3
	<i>Taurotragus oryx</i>	Eland.....	3

BIRDS

STRUTHIONIFORMES

Struthionidae:			
	<i>Struthio camelus</i>	Ostrich.....	1

RHEIFORMES

Rheidae:			
	<i>Rhea americana</i>	Common rhea.....	3

CASUARIFORMES

Casuariidae:			
	<i>Casuarus casuarus aruensis</i>	Aru cassowary.....	1
	<i>Casuarus unappendiculatus occipitalis</i>	Island cassowary.....	1
	<i>Casuarus unappendiculatus unappendiculatus</i>	One-wattled cassowary.....	1
Dromiceidae:			
	<i>Dromiceus novaehollandiae</i>	Common emu.....	2

Scientific name		TINAMIFORMES	Common name	Number
Tinamidae:				
<i>Crypturellus variegatus</i>		Variegated tinamou.....		1
SPHENISCIFORMES				
Spheniscidae:				
<i>Aptenodytes forsteri</i>		Emperor penguin.....		1
<i>Eudyptes chrysolophus</i>		Macaroni penguin.....		1
<i>Spheniscus demersus</i>		Jackass penguin.....		3
<i>Spheniscus humboldti</i>		Humboldt's penguin.....		1
PELECANIFORMES				
Pelecanidae:				
<i>Pelecanus erythrorhynchus</i>		White pelican.....		2
<i>Pelecanus occidentalis californicus</i> ...		California brown pelican.....		2
<i>Pelecanus occidentalis occidentalis</i> ...		Brown pelican.....		2
<i>Pelecanus roseus</i>		Rose-colored pelican.....		2
Sulidae:				
<i>Sula leucogaster</i>		Brown booby.....		1
Phalacrocoracidae:				
<i>Phalacrocorax auritus albociliatus</i> ...		Farallon cormorant.....		1
<i>Phalacrocorax auritus auritus</i>		Double-crested cormorant.....		1
CICONIIFORMES				
Ardeidae:				
<i>Ardea herodias</i>		Great blue heron.....		2
<i>Hydranassa tricolor ruficollis</i>		Louisiana heron.....		1
<i>Leucophoyx thula</i>		Snowy egret.....		6
<i>Notophoyx novaehollandiae</i>		White-faced heron.....		1
<i>Nycticorax nycticorax hoactli</i>		Black-crowned night heron.....		29
Cochleariidae:				
<i>Cochlearius cochlearius</i>		Boat-billed heron.....		1
Ciconiidae:				
<i>Ciconia alba</i>		White stork.....		2
<i>Ibis cinereus</i>		Malayan painted stork.....		1
<i>Jabiru mycteria</i>		Jabiru.....		2
<i>Leptoptilus crumeniferus</i>		Marabou.....		1
<i>Leptoptilus dubius</i>		Indian adjutant.....		1
<i>Leptoptilus javanicus</i>		Lesser adjutant.....		2
<i>Mycteria americana</i>		Wood ibis.....		1
Threskiornithidae:				
<i>Ajaia ajaja</i>		Roseate spoonbill.....		3
<i>Guara alba</i>		White ibis.....		4
<i>Guara alba</i> × <i>G. rubra</i>		Hybrid, white ibis × scarlet ibis.....		1
<i>Guara rubra</i>		Scarlet ibis.....		3
<i>Threskiornis melanocephala</i>		Black-headed ibis.....		1
Phoenicopteridae:				
<i>Phoenicopiterus antiquorum</i>		Old World flamingo.....		2
<i>Phoenicopiterus chilensis</i>		Chilean flamingo.....		7
<i>Phoenicopiterus ruber</i>		Cuban flamingo.....		1

ANSERIFORMES

Scientific name	Common name	Number
Anhimidae:		
<i>Chauna torquata</i>	Crested screamer	4
Anatidae:		
<i>Aix sponsa</i>	Wood duck	3
<i>Anas bahamensis</i>	Bahama pintail	2
<i>Anas brasiliensis</i>	Brazilian teal	1
<i>Anas platyrhynchos</i>	Mallard duck	20
	White mallard duck	3
<i>Anas platyrhynchos</i> × <i>Dafila acuta</i> ..	Hybrid, mallard duck × pintail duck	1
<i>Anas platyrhynchos domestica</i>	Pekin duck	20
<i>Anas rubripes</i>	Black duck	3
<i>Anser albifrons</i>	Greenland white-fronted goose ..	1
<i>Anser anser domestica</i>	Toulouse goose	4
<i>Anseranas semipalmata</i>	Australian pied goose	1
<i>Aythya affinis</i>	Lesser scaup	1
<i>Aythya fuligula</i>	Tufted duck	4
<i>Aythya valisineria</i>	Canvasback duck	2
<i>Branta canadensis</i>	Canada goose	26
<i>Branta canadensis</i> × <i>Chen caerulescens</i>	Hybrid, Canada goose × blue goose	2
<i>Branta canadensis occidentalis</i>	White-cheeked goose	16
<i>Branta hutchinsii</i>	Hutchins's goose	3
<i>Branta hutchinsii minima</i>	Cackling goose	20
<i>Branta ruficollis</i>	Red-breasted goose	2
<i>Cairina moschata</i>	Muscovy duck	7
<i>Cereopsis novaehollandiae</i>	Cape Barren goose	1
<i>Chen atlantica</i>	Snow goose	3
<i>Chen caerulescens</i>	Blue goose	3
<i>Chen hyperborea</i>	Lesser snow goose	2
<i>Chenopsis atrata</i>	Black swan	9
<i>Chloephaga leucoptera</i>	Upland goose	2
<i>Coscoroba coscoroba</i>	Coscoroba	1
<i>Cygnopsis cygnoides</i>	Domestic swan-goose	3
<i>Cygnus columbianus</i>	Whistling swan	5
<i>Cygnus cygnus</i>	Whooper swan	2
<i>Cygnus melanoriphus</i>	Black-necked swan	1
<i>Dafila acuta</i>	Pintail	7
<i>Dafila spinicauda</i>	Chilean pintail	1
<i>Dendrocygna autumnalis</i>	Black-bellied tree duck	3
<i>Dendrocygna viduata</i>	White-faced tree duck	2
<i>Mareca americana</i>	Baldpate	1
<i>Metopiana peposaca</i>	Rosy-billed pouchard	2
<i>Nettion carolinense</i>	Green-winged teal	3
<i>Nettion formosum</i>	Baikal teal	2
<i>Philacte canagica</i>	Emperor goose	2
<i>Plectropterus gambiensis</i>	Spur-winged goose	2
<i>Querquedula discors</i>	Blue-winged teal	2

Scientific name		FALCONIFORMES	Common name	Number
Cathartidae:				
<i>Cathartes aura</i>			Turkey vulture.....	1
<i>Coragyps atratus</i>			Black vulture.....	7
<i>Sarcoramphus papa</i>			King vulture.....	2
<i>Vultur gryphus</i>			Andean condor.....	2
Sagittariidae:				
<i>Sagittarius serpentarius</i>			Secretarybird.....	2
Accipitridae:				
<i>Accipiter cooperi</i>			Cooper's hawk.....	1
<i>Buteo jamaicensis</i>			Red-tailed hawk.....	5
<i>Buteo lineatus lineatus</i>			Red-shouldered hawk.....	4
<i>Buteo melanoleucus</i>			South American buzzard eagle..	2
<i>Buteo platypterus</i>			Broad-winged hawk.....	1
<i>Buteo poecilochrous</i>			Red-backed buzzard.....	1
<i>Buteo swainsoni</i>			Swainson's hawk.....	1
<i>Gyps rueppelli</i>			Rüppell's vulture.....	2
<i>Haliaeetus leucocephalus</i>			Bald eagle.....	7
<i>Haliaeetus leucogaster</i>			White-breasted sea eagle.....	2
<i>Haliastur indus</i>			Brahminy kite.....	3
<i>Harpia harpya</i>			Harpy eagle.....	1
<i>Milvago chimango</i>			Chimango.....	3
<i>Milvus migrans parasitus</i>			African yellow-billed kite.....	2
<i>Pandion haliaetus carolinensis</i>			Osprey.....	2
<i>Parabuteo unicinctus</i>			One-banded hawk.....	1
<i>Pithecophaga jefferyi</i>			Monkey-eating eagle.....	1
<i>Spiziastur melanoleucus</i>			Black-and-white hawk eagle...	1
Falconidae:				
<i>Falco mexicanus</i>			Prairie falcon.....	1
<i>Falco peregrinus anatum</i>			Duck hawk.....	1
<i>Falco sparverius</i>			Sparrow hawk.....	5
<i>Polyborus plancus</i>			South American caracara.....	3
GALLIFORMES				
Megapodiidae:				
<i>Alectura lathamii</i>			Brush turkey.....	2
Cracidae:				
<i>Crax fasciolata</i>			Crested curassow.....	2
<i>Crax fasciolata sclateri</i>			Sclater's curassow.....	1
<i>Crax rubra</i>			Panama curassow.....	1
<i>Mitu mitu</i>			Razor-billed curassow.....	1
<i>Penelope boliviana</i>			Crested guan.....	3
Phasianidae:				
<i>Argusianus argus</i>			Argus pheasant.....	1
<i>Chrysolophus amherstiae</i>			Lady Amherst's pheasant.....	1
<i>Chrysolophus pictus</i>			Golden pheasant.....	2
<i>Colinus cristatus</i>			Crested quail.....	11
<i>Colinus virginianus</i>			Bobwhite.....	1
<i>Crossoptilon auritum</i>			Blue-eared pheasant.....	1
<i>Francolinus coqui</i>			Coqui francolin.....	2
<i>Gallus gallus</i>			Bantam fowl.....	70
<i>Gallus gallus</i>			Oriental silky bantam fowl....	2

Scientific name	Common name	Number
Phasianidae—Continued		
<i>Gallus gallus</i>	Fighting fowl.....	10
<i>Gallus gallus</i>	Red jungle fowl.....	7
<i>Gallus gallus</i>	Hybrid, red jungle fowl × bantam fowl.....	1
<i>Gallus lafayettii</i>	Ceylonese jungle fowl.....	1
<i>Gallus sonneratii</i>	Gray jungle fowl.....	1
<i>Gennaeus albocristatus</i>	White-crested kaleege.....	1
<i>Gennaeus leucomelanus</i>	Nepal kaleege.....	11
<i>Gennaeus nychemerus</i>	Silver pheasant.....	2
<i>Hierophasis swinhoii</i>	Swinhoe's pheasant.....	1
<i>Odontophorus gujanensis marmoratus</i>	Marbled Guiana quail.....	1
<i>Pavo cristatus</i>	Peafowl.....	5
<i>Phasianus torquatus</i>	Ring-necked pheasant.....	4
<i>Syrnaticus reevesi</i>	Reeves's pheasant.....	1
Numididae:		
<i>Acryllium vulturinum</i>	Vulturine guinea fowl.....	1
<i>Numida</i> sp.....	Guinea fowl.....	1
<i>Guttera eduardi schoutedeni</i>	Schouteden's crested guinea fowl.....	1
<i>Guttera plumifera schubotzi</i>	Uele crested guinea fowl.....	2
Meleagrididae:		
<i>Agriocharis ocellata</i>	Ocellated turkey.....	3
<i>Meleagris gallopavo</i>	Wild turkey.....	2
GRUIFORMES		
Gruidae:		
<i>Anthropoides virgo</i>	Demoiselle crane.....	2
<i>Balearica pavonina</i>	West African crowned crane....	2
<i>Balearica regulorum gibbericeps</i>	East African crowned crane....	1
<i>Grus leucauchen</i>	White-naped crane.....	1
<i>Grus leucogeranus</i>	Siberian crane.....	2
Psophiidae:		
<i>Psophia leucoptera</i>	White-backed trumpeter.....	1
Rallidae:		
<i>Amaurornis phoenicurus</i>	White-breasted rail.....	1
<i>Aramides cajanea</i>	Wood rail.....	2
<i>Fulica americana</i>	American coot.....	8
<i>Gallinula chloropus cachinnans</i>	Florida gallinule.....	3
<i>Gallinula chloropus indica</i>	Indian gallinule.....	2
<i>Ironornis martinica</i>	Purple gallinule.....	1
<i>Laterallus viridis</i>	Cayenne rail.....	2
<i>Rallus limicola limicola</i>	Virginia rail.....	1
Cariamidae:		
<i>Cariama cristata</i>	Cariama or seriema.....	2
Eurypygidae:		
<i>Eurypyga major</i>	Sun bittern.....	2
CHARADRIIFORMES		
Recurvirostridae:		
<i>Himantopus mexicanus</i>	Black-necked stilt.....	2
Burhinidae:		
<i>Burhinus bistriatus</i>	South American thick-knee....	1

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Haematopodidae:		
<i>Haematopus ostralegus</i>	European oystercatcher.....	3
Charadriidae:		
<i>Belonopterus chilensis</i>	Chilean lapwing.....	2
<i>Philomachus pugnax</i>	Ruff.....	5
Laridae:		
<i>Larus argentatus</i>	Herring gull.....	1
<i>Larus delawarensis</i>	Ring-billed gull.....	2
<i>Larus dominicanus</i>	Kelp gull.....	2
<i>Larus novaehollandiae</i>	Silver gull.....	6

COLUMBIFORMES

Columbidae:		
<i>Columba livia</i>	Domestic pigeon.....	9
<i>Columba nigrirostris</i>	Short-billed pigeon.....	1
<i>Columbigallina minuta elaeodes</i>	Ground dove.....	2
<i>Ducula paulina</i>	Celebian imperial pigeon.....	1
<i>Gallicolumba luzonica</i>	Bleeding-heart dove.....	2
<i>Gallicolumba luzonica</i> × <i>Streptopelia</i> <i>decaocto</i>	Hybrid, bleeding-heart dove × ring-necked dove.....	1
<i>Goura victoria</i>	Victoria crowned pigeon.....	1
<i>Oreopeleia montana</i>	Ruddy quail dove.....	2
<i>Streptopelia tranquebarica</i>	Blue-headed ring dove.....	17
<i>Streptopelia decaocto</i>	Ring-necked dove.....	15
<i>Zenaida asiatica</i>	White-winged dove.....	12
<i>Zenaidura auriculata</i>	South American mourning dove.....	4
<i>Zenaidura macroura</i>	Mourning dove.....	2

PSITTACIFORMES

Psittacidae:		
<i>Agapornis lilianae</i>	Red-faced lovebird.....	2
<i>Amazona aestiva</i>	Blue-fronted parrot.....	1
<i>Amazona auropalliata</i>	Yellow-naped parrot.....	4
<i>Amazona ochrocephala</i>	Yellow-headed parrot.....	4
<i>Amazona oratrix</i>	Double yellow-headed parrot.....	8
<i>Anodorhynchus hyacinthinus</i>	Hyacinthine macaw.....	1
<i>Ara ararauna</i>	Yellow-and-blue macaw.....	7
<i>Ara macao</i>	Red, blue, and yellow macaw.....	6
<i>Aratinga euops</i>	Cuban conure.....	1
<i>Brotogeris jugularis</i>	Tovi parakeet.....	12
<i>Calyptrorhynchus magnificus</i>	Banksian cockatoo.....	1
<i>Conurus weddelli</i>	Weddell's conure.....	5
<i>Domicella garrula</i>	Red lory.....	1
<i>Kakatoe alba</i>	White cockatoo.....	2
<i>Kakatoe ducrops</i>	Solomon Islands cockatoo.....	2
<i>Kakatoe galerita</i>	Large sulphur-crested cockatoo.....	3
<i>Kakatoe moluccensis</i>	Great red-crested cockatoo.....	1
<i>Kakatoe sanguineus</i>	Bare-eyed cockatoo.....	1
<i>Neophema chrysostoma</i>	Blue-winged parrot.....	2
<i>Nestor notabilis</i>	Kea.....	1
<i>Nymphicus hollandicus</i>	Cockatiel.....	1

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Psittacidae—Continued		
<i>Pionus menstruus</i>	Blue-headed conure.....	1
<i>Psittacula eupatria</i>	Red-shouldered parakeet.....	1
<i>Psittacula krameri</i>	Kramer's parakeet.....	1

CUCULIFORMES

Cuculidae:		
<i>Eudynamys scolopacea</i>	Koel.....	1
Musophagidae:		
<i>Tauraco corythaix</i>	South African turaco.....	2
<i>Tauraco donaldsoni</i>	Donaldson's turaco.....	1
<i>Tauraco persa</i>	Purple turaco.....	2

STRIGIFORMES

Tytonidae:		
<i>Tyto alba pratincola</i>	Barn owl.....	10
Strigidae:		
<i>Bubo virginianus</i>	Great horned owl.....	8
<i>Ketupa ketupu</i>	Malay fishing owl.....	1
<i>Nyctea nyctea</i>	Snowy owl.....	1
<i>Otus asio</i>	Screech owl.....	4
<i>Strix varia varia</i>	Barred owl.....	11

CORACIIFORMES

Alcedinidae:		
<i>Dacelo gigas</i>	Kookaburra.....	2
Coraciidae:		
<i>Anthracoceros coronatus</i>	Pied hornbill.....	2
Momotidae:		
<i>Baryphengus martii</i>	Great rufous motmot.....	1
<i>Momotus lessoni</i>	Lesson's motmot.....	1

PICIFORMES

Capitonidae:		
<i>Megalaima asiatica</i>	Blue-throated barbet.....	1
Ramphastidae:		
<i>Pteroglossus inscriptus</i>	Yellow-billed toucanet.....	1
<i>Ramphastos ariel</i>	Ariel toucan.....	2
<i>Ramphastos carinatus</i>	Sulphur-breasted toucan.....	3
<i>Ramphastos culminatus</i>	White-breasted toucan.....	1
<i>Ramphastos piscivorus</i>	Toco toucan.....	1

PASSERIFORMES

Cotingidae:		
<i>Rupicola rupicola</i>	Cock-of-the-rock.....	2
Dieruridae:		
<i>Dissemurus paradiseus</i>	Giant racquet-tailed drongo.....	1
Oriolidae:		
<i>Zarhynchus wagleri</i>	Wagler's oropendula.....	1
Corvidae:		
<i>Corvus brachyrhynchos</i>	American crow.....	8
<i>Corvus corax principalis</i>	Northern raven.....	1

Scientific name	Common name	Number
Corvidae—Continued		
<i>Corvus cornix</i>	Hooded crow.....	1
<i>Corvus cryptoleucus</i>	White-necked raven.....	1
<i>Corvus insolens</i>	Indian crow.....	2
<i>Corvus monedula</i>	Jackdaw.....	3
<i>Cyanocitta cristata</i>	Blue jay.....	8
<i>Cyanocorax chrysops</i>	Urraca jay.....	1
<i>Garrulus glandarius</i>	European jay.....	1
<i>Gymnorhina hypoleuca</i>	White-backed piping crow.....	1
<i>Pica nuttalli</i>	Yellow-billed magpie.....	1
<i>Pica pica hudsonica</i>	American magpie.....	2
<i>Urocissa caerulea</i>	Formosan red-billed pie.....	2
Paradisidae:		
<i>Paradisa apoda</i>	Great bird-of-paradise.....	1
<i>Ptilonorhynchus violaceus</i>	Satin bowerbird.....	1
Timaliidae:		
<i>Garrulax bicolor</i>	White-headed laughing thrush..	2
Pycnonotidae:		
<i>Heterophasia capistrata</i>	Black-headed sibia.....	2
<i>Pycnonotus analis</i>	Yellow-vented bulbul.....	1
<i>Pycnonotus leucogenys</i>	White-cheeked bulbul.....	1
Mimidae:		
<i>Mimus polyglottos polyglottos</i>	Eastern mockingbird.....	1
<i>Mimus polyglottos leucopterus</i>	Western mockingbird.....	2
<i>Toxostoma rufum</i>	Brown thrasher.....	2
Turdidae:		
<i>Geokichla citrina</i>	Orange-headed ground thrush...	1
<i>Hylocichla mustelina</i>	Wood thrush.....	1
<i>Platycichla flavipes</i>	Yellow-footed thrush.....	1
<i>Turdus grayi</i>	Bonaparte's thrush.....	1
<i>Turdus migratorius</i>	Eastern robin.....	3
Sturnidae:		
<i>Acridotheres tristis</i>	Common mynah.....	1
<i>Gracula religiosa</i>	Southern hill mynah.....	1
<i>Gracupica melanopectera</i>	White starling.....	1
<i>Lamprocolius splendens</i>	Splendid glossy starling.....	3
<i>Lamprotornis australis</i>	Burchell's glossy starling.....	1
<i>Sturnia malabarica</i>	Gray-headed mynah.....	1
Parulidae:		
<i>Dendroica pinus</i>	Pine warbler.....	1
<i>Seiurus aurocapillus</i>	Ovenbird.....	2
Ploceidae:		
<i>Aegintha temporalis</i>	Sydney waxbill.....	8
<i>Aidemosyne cantans</i>	Tawny waxbill.....	3
<i>Aidemosyne malabarica</i>	Indian silverbill.....	2
<i>Aidemosyne modesta</i>	Plum-headed finch.....	2
<i>Alisteranus cinctus</i>	Parson finch.....	2
<i>Amadina fasciata</i>	Cut-throat weaver finch.....	6
<i>Amandava amandava</i>	Strawberry finch.....	3
<i>Cayleya picta</i>	Painted finch.....	1
<i>Diatropura procne</i>	Giant whydah.....	2
<i>Estrilda astrild</i>	Red-eared waxbill.....	10

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Ploceidae—Continued		
<i>Euplectes franciscana</i>	Bishop weaver.....	3
<i>Hypochera ultramarina</i>	Combasou or indigobird.....	1
<i>Lagonosticta senegalla</i>	African fire finch.....	2
<i>Lonchura leucogastroides</i>	Bengali finch.....	2
<i>Munia maja</i>	White-headed munia.....	2
<i>Munia malacca</i>	Black-throated munia.....	1
<i>Munia punctulata</i>	Spice finch.....	3
<i>Padda oryzivora</i>	Java sparrow.....	15
<i>Passer domesticus</i>	House sparrow.....	3
<i>Ploceus baya</i>	Baya weaver.....	2
<i>Ploceus intermedius</i>	Black-cheeked weaver.....	2
<i>Ploceus vitellinus</i>	Vitelline masked weaver.....	6
<i>Poephila cuticauda</i>	Long-tailed finch.....	1
<i>Poephila personata</i>	Masked finch.....	2
<i>Quelea quelea</i>	Red-billed weaver.....	4
<i>Sporaeginthus melopodus</i>	Orange-cheeked waxbill.....	5
<i>Steganopleura bichenovii</i>	Bicheno's finch.....	1
<i>Steganura paradisea</i>	Paradise whydah.....	12
<i>Taeniopygia castanotis</i>	Zebra finch.....	3
<i>Uraeginthus bengalus</i>	Cordon-bleu finch.....	7
Coerebidae:		
<i>Cyanerpes cyaneus</i>	Blue honeycreeper.....	14
Icteridae:		
<i>Agelaius assimilis</i>	Cuban red-winged blackbird.....	2
<i>Amblyramphus holosericeus</i>	Scarlet-headed blackbird.....	1
<i>Gymnomystax mexicanus</i>	Giant oriole.....	1
<i>Icterus bullocki</i>	Bullock's troupial.....	1
<i>Icterus giraudi</i>	Giraud's oriole.....	1
<i>Molothrus bonariensis</i>	Shiny cowbird.....	1
<i>Notiopsar curaeus</i>	Chilean blackbird.....	2
<i>Peziles defilippii</i>	Military starling.....	4
<i>Quiscalus quiscula</i>	Purple grackle.....	1
<i>Xanthocephalus xanthocephalus</i>	Yellow-headed blackbird.....	1
<i>Xanthornis angustifrons</i>	Oropendula.....	1
Thraupidae:		
<i>Calospiza inornata languens</i>	Plain-colored tanager.....	1
<i>Calospiza ruficollis</i>	Brown-headed tanager.....	1
<i>Piranga erythromelas</i>	Scarlet tanager.....	2
<i>Ramphocelus carbo</i>	Silver-beaked tanager.....	2
<i>Ramphocelus dimidiatus</i>	Crimson tanager.....	2
<i>Ramphocelus flammigerus</i>	Yellow tanager.....	2
<i>Ramphocelus passerinii</i>	Passerini's tanager.....	1
<i>Thraupis bonariensis darwini</i>	Darwin's tanager.....	2
<i>Thraupis cana</i>	Blue tanager.....	1
Fringillidae:		
<i>Carpodacus mexicanus</i>	Mexican house finch.....	2
<i>Carpodacus purpureus californicus</i>	California purple finch.....	3
<i>Coryphospingus cucullatus</i>	Red-crested finch.....	1
<i>Cyanocompsa argentina</i>	Argentine blue grosbeak.....	2
<i>Diuca diuca</i>	Diuca finch.....	1
<i>Lophospingus pusillus</i>	Black-crested finch.....	2

Scientific name	Common name	Number
Fringillidae—Continued		
<i>Melopyrrha nigra</i>	Cuban bullfinch.....	2
<i>Melospiza melodia</i>	Song sparrow.....	3
<i>Paroaria cucullata</i>	Brazilian cardinal.....	1
<i>Paroaria gularis nigro-genis</i>	Black-eared cardinal.....	1
<i>Passerella iliaca</i>	Fox sparrow.....	1
<i>Passerina amoena</i>	Lazuli bunting.....	1
<i>Passerina ciris</i>	Painted bunting.....	1
<i>Passerina cyanea</i>	Indigo bunting.....	2
<i>Passerina leclancheri</i>	Leclancher's bunting.....	1
<i>Passerina versicolor</i>	Varied bunting.....	1
<i>Pheucticus aureoventris</i>	Black-and-yellow grosbeak.....	2
<i>Phrygilus alaudinus</i>	Chilean lark finch.....	1
<i>Phrygilus fruticeti</i>	Mourning finch.....	2
<i>Phrygilus gayi</i>	Gay's gray-headed finch.....	1
<i>Poospiza torquata</i>	Ringed warbling finch.....	2
<i>Richmondia cardinalis</i>	Cardinal.....	3
<i>Serinus canarius</i>	Canary.....	7
<i>Serinus canarius</i> × <i>Carduelis mexi-</i> <i>cana</i>	Hybrid, canary × siskin.....	2
<i>Serinus icterus</i>	Green singing finch.....	1
<i>Sicalis flaveola</i>	Mysto finch.....	1
<i>Sicalis luteola</i>	Saffron finch.....	3
<i>Sicalis minor</i>	Lesser yellow finch.....	4
<i>Spinus uropygialis</i>	Chilean siskin.....	1
<i>Sporophila aurita</i>	Hicks's seedeater.....	1
<i>Sporophila gutturalis</i>	Yellow-billed seedeater.....	1
<i>Sporophila melanocephala</i>	Black-headed seedeater.....	2
<i>Tiaris olivacea</i>	Mexican grassquit.....	3
<i>Volatinia jacarina</i>	Blue-black grassquit.....	1
<i>Zonotrichia albicollis</i>	White-throated sparrow.....	4
<i>Zonotrichia capensis</i>	Chingolo.....	1

REPTILES

LORICATA

Crocodylidae:

<i>Alligator mississippiensis</i>	Alligator.....	33
<i>Alligator sinensis</i>	Chinese alligator.....	2
<i>Caiman latirostris</i>	Broad-snouted caiman.....	1
<i>Caiman sclerops</i>	Spectacled caiman.....	4
<i>Crocodylus acutus</i>	American crocodile.....	3
<i>Crocodylus cataphractus</i>	Narrow-nosed crocodile.....	1
<i>Crocodylus niloticus</i>	African crocodile.....	2
<i>Crocodylus palustris</i>	"Toad" crocodile.....	2
<i>Crocodylus porosus</i>	Salt-water crocodile.....	1
<i>Osteolaemus tetraspis</i>	Broad-nosed crocodile.....	3

SQUAMATA

SAURIA			
Scientific name	Common name		Number
Agamidae:			
<i>Physignathus lesueuri</i>	Lesueur's water dragon.....		4
<i>Uromastix acanthinurus</i>	North African spiny-tailed lizard.....		1
Xenosauridae:			
<i>Xenosaurus laticaudatus</i>	Broad-tailed lizard.....		1
Iguanidae:			
<i>Anolis carolinensis</i>	American anolis or false cha- meleon.....		10
<i>Anolis equestris</i>	Giant anolis.....		2
<i>Anolis sagrae</i>	Giant anolis.....		1
<i>Basiliscus vittatus</i>	Basilisk.....		4
<i>Conolophus subcristatus</i>	Galápagos iguana.....		2
<i>Phrynosoma cornutum</i>	Horned lizard.....		6
<i>Sceloporus undulatus</i>	Pine or fence lizard.....		6
Zonuridae:			
<i>Zonosaurus ornatus</i>	Ornate lizard.....		1
<i>Zonurus giganteus</i>	African spiny lizard.....		1
Helodermatidae:			
<i>Heloderma horridum</i>	Mexican beaded lizard.....		2
<i>Heloderma suspectum</i>	Gila monster.....		4
Lacertidae:			
<i>Eremias mucronata</i>	Egyptian sand lizard.....		3
Teiidae:			
<i>Cnemidophorus bocourti</i>	Whiptail lizard.....		1
Scincidae:			
<i>Egernia cunninghami</i>	Cunningham's skink.....		3
<i>Egernia luctuosa</i>	Mourning skink.....		2
<i>Egernia whitii</i>	White's skink.....		10
<i>Eumeces fasciatus</i>	Blue-tailed skink.....		2
<i>Tiliqua scincoides</i>	Blue-tongued lizard.....		4
Chameleontidae:			
<i>Chameleon dilepis</i>	Chameleon.....		1

SERPENTES

Typhlopidae:			
<i>Typhlops</i> sp.....	African burrowing snake.....		1
Boidae:			
<i>Boa canina</i>	Green tree boa.....		1
<i>Boa dumerilii</i>	Duméril's boa.....		1
<i>Constrictor constrictor</i>	Boa constrictor.....		2
<i>Constrictor imperator</i>	Central American boa.....		36
<i>Constrictor mexicanus</i>	Southern boa.....		1
<i>Epicrates cenchria</i>	Rainbow boa.....		11
<i>Eunectes murinus</i>	Anaconda.....		1
<i>Python molurus</i>	Indian rock python.....		13
<i>Python regius</i>	Ball python.....		1
<i>Python reticulatus</i>	Regal python.....		6
<i>Python spilotes</i>	Diamond python.....		1
<i>Python variegatus</i>	Carpet python.....		4

Scientific name	Common name	Number
Colubridae:		
<i>Arizona elegans eburnata</i>	Glossy snake.....	1
<i>Boaedon fuliginosus</i>	House snake.....	1
<i>Boaedon lineatum</i>	Brown house snake.....	1
<i>Carphophis amoena</i>	Worm snake.....	1
<i>Chlorophis heterolepidota</i>	Bush snake.....	3
<i>Coluber constrictor</i>	Black snake.....	1
<i>Dasyptellus scabra</i>	Egg-eating snake.....	1
<i>Diadophis punctatus</i>	Ring-necked snake.....	2
<i>Drymarchon corais couperi</i>	Indigo snake.....	3
<i>Elaphe guttata</i>	Corn snake.....	1
<i>Elaphe obsoleta</i>	Pilot snake.....	7
<i>Elaphe quadrivittata</i>	Chicken snake.....	1
<i>Elaphe vulpina</i>	Fox snake.....	1
<i>Eryx thebaicus</i>	Dassa's snake.....	4
<i>Heterodon contortrix</i>	Hog-nosed snake.....	1
<i>Lampropeltis getulus boylii</i>	Boyle's king snake.....	1
<i>Lampropeltis getulus getulus</i>	Chain king snake.....	4
<i>Lampropeltis rhombomaculata</i>	Mole snake.....	3
<i>Lampropeltis triangulum triangulum</i>	Milk snake or spotted adder.....	1
<i>Natrix sipedon</i>	Banded water snake.....	3
<i>Natrix</i> sp.....	Water snake.....	6
<i>Ophedrys vernalis</i>	Smooth-scaled green snake.....	1
<i>Oxybelis acuminatus</i>	Pike-head snake.....	1
<i>Ptyas mucosus</i>	Indian rat snake.....	1
<i>Storeria dekayi</i>	DeKay's snake.....	2
<i>Thamnophis sirtalis</i>	Garter snake.....	7
Elapidae:		
<i>Bungarus fasciatus</i>	Banded krait.....	2
<i>Naja haje</i>	Egyptian cobra.....	1
<i>Naja hannah</i>	King cobra.....	1
<i>Naja melanoleuca</i>	West African cobra.....	1
Viperidae:		
<i>Bitis arietans</i>	Puff adder.....	2
Crotalidae:		
<i>Agkistrodon mokeson</i>	Copperhead snake.....	3
<i>Agkistrodon piscivorus</i>	Cottonmouth moccasin.....	10
<i>Bothrops lanceolatus</i>	Fer-de-lance.....	3
<i>Crotalus terrificus basiliscus</i>	Mexican rattlesnake.....	6

TESTUDINATA

Chelydridae:

<i>Batrachemys nasuta</i>	South American side-necked turtle.....	2
<i>Chelodina longicollis</i>	Australian long-necked turtle.....	2
<i>Hydraspis</i> sp.....	Cagado or South American snake-necked turtle.....	1
<i>Hydromedusa tectifera</i>	South American snake-necked turtle.....	14
<i>Platemys platycephala</i>	Flat-headed turtle.....	1

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
Kinosternidae:		
<i>Kinosternon subrubrum</i>	Mud turtle.....	5
<i>Sternotherus odoratus</i>	Musk turtle.....	4
Chelydridae:		
<i>Chelydra serpentina</i>	Snapping turtle.....	8
<i>Macrochelys temminckii</i>	Alligator snapping turtle.....	1
Testudinidae:		
<i>Batagur baska</i>	Indian fresh-water turtle.....	1
<i>Chrysemys picta</i>	Painted turtle.....	7
<i>Clemmys guttata</i>	Spotted turtle.....	6
<i>Clemmys insculpta</i>	Wood turtle.....	4
<i>Cyclemys amboinensis</i>	Kura kura box turtle.....	1
<i>Emydura krefftii</i>	Krefft's turtle.....	3
<i>Emydura macquariae</i>	Murra turtle.....	11
<i>Gopherus berlandieri</i>	Berlandier's turtle.....	4
<i>Graptemys barbouri</i>	Barbour's turtle.....	8
<i>Kinixys belliana</i>	Hinge-backed turtle.....	1
<i>Malaclemys centrata</i>	Diamondback turtle.....	3
<i>Pelomedusa galeata</i>	Common African water turtle.....	1
<i>Pelusios nigricans</i>	Black African water turtle.....	7
<i>Pseudemys concinna</i>	Cooter.....	1
<i>Pseudemys elegans</i>	Mobile turtle.....	12
<i>Pseudemys ornata</i> subsp.....	Central American turtle.....	6
<i>Terrapene carolina</i>	Box turtle.....	50
<i>Terrapene major</i>	Florida box turtle.....	4
<i>Testudo ephippium</i>	Duncan Island turtle.....	2
<i>Testudo hoodensis</i>	Hood Island turtle.....	2
<i>Testudo tabulata</i>	South American turtle.....	3
<i>Testudo vicina</i>	Albemarle Island turtle.....	5
Trionychidae:		
<i>Amyda ferox</i>	Soft-shelled turtle.....	17
<i>Amyda triunguis</i>	West African soft-shelled turtle.....	1

AMPHIBIA

CAUDATA

Salamandridae:		
<i>Triturus cristatus danubialis</i>	European crested newt.....	2
<i>Triturus pyrrhogaster</i>	Red Japanese salamander.....	1
<i>Triturus torosus</i>	Giant newt.....	14
<i>Triturus viridescens</i>	Common newt (of the United States).....	3
<i>Triturus vulgaris</i>	Common European salamander.....	3
Amphiumidae:		
<i>Amphiuma means</i>	Congo eel.....	1
Ambystomidae:		
<i>Ambystoma tigrinum</i>	Tiger salamander.....	6
Cryptobranchidae:		
<i>Cryptobranchus alleganiensis</i>	Hellbender.....	10
<i>Megalobatrachus japonicus</i>	Giant Japanese salamander.....	1

SALIENTIA		
Scientific name	Common name	Number
Dendrobatidae:		
<i>Atelopus varius cruciger</i>	Yellow atelopus.....	14
<i>Dendrobates auratus</i>	Arrow-poison frog.....	6
Bufo		
<i>Bufo alvarius</i>	Western green toad.....	4
<i>Bufo americanus</i>	Common toad.....	1
<i>Bufo empusus</i>	Sapo de concha.....	1
<i>Bufo marinus</i>	Marine toad.....	11
<i>Bufo peltacephalus</i>	Cuban giant toad.....	1
Discoglossidae:		
<i>Bombina bombina</i>	Red-bellied toad.....	2
Leptodactylidae:		
<i>Ceratophrys ornata</i>	Horned frog.....	4
Pipidae:		
<i>Pipa pipa</i>	Surinam toad.....	1
<i>Xenopus laevis</i>	African clawed frog.....	5
<i>Xenopus mülleri</i>	Müller's clawed frog.....	16
Ranidae:		
<i>Hyperolius</i> sp.....	African green tree frog.....	1
<i>Hyperolius</i> sp.....	Broad-striped African tree frog.....	12
<i>Hyperolius</i> sp.....	Narrow-striped African tree frog.....	2
<i>Hyperolius</i> sp.....	Red-legged African tree frog.....	5
<i>Rana adspersa</i>	African bull frog.....	3
<i>Rana catesbiana</i>	Bull frog.....	6
<i>Rana clamitans</i>	Green frog.....	2
<i>Rana pipiens</i>	Leopard frog.....	10

FISHES

<i>Anabas testudineus</i>	Climbing perch.....	4
<i>Anoptichthys jordani</i>	Blind characin.....	6
<i>Aphyosemion sjoestedti</i>	Red fundulus.....	2
<i>Barbus everetti</i>	Clown barb.....	2
<i>Barbus oligolepis</i>	Tiger barb.....	25
<i>Barbus partipentazona</i>	Banded barb.....	2
<i>Brachydanio albolineatus</i>	Pearl danio.....	2
<i>Brachydanio rerio</i>	Zebra danio.....	1
<i>Carassius auratus</i>	Goldfish.....	1
<i>Channa asiatica</i>	Snakehead.....	1
<i>Corydoras</i> sp.....	South American catfish.....	2
<i>Danio malabaricus</i>	Blue danio.....	2
<i>Gymnocorymbus ternetzi</i>	Black tetra.....	14
<i>Hemichromis bimaculatus</i>	Jewelfish.....	1
<i>Hemigrammus ocellifer</i>	Head- and tail-light fish.....	2
<i>Hyphessobrycon innesi</i>	Neon tetra.....	25
<i>Lebistes reticulatus</i>	Guppy.....	100
<i>Lepidosiren paradoxa</i>	South American lungfish.....	2
<i>Loricaria</i> sp.....	2
<i>Mesonauta insignis</i>	1
<i>Otocinclus affinis</i>	Sucker catfish.....	1

<i>Scientific name</i>	<i>Common name</i>	<i>Number</i>
<i>Platypoecilus maculatus</i>	{ Wagtail platy.....	4
	{ Red platy.....	10
<i>Platypoecilus punctatus</i>	Moonfish.....	3
<i>Poecilobrycon unifasciatus</i>	Pencilfish.....	1
<i>Pristella riddlei</i>	Tetra.....	7
<i>Protopterus annectens</i>	African lungfish.....	2
<i>Rasbora heteramorphas</i>	Rasbora fish.....	30
<i>Tanichthys albonubes</i>	White cloud mountainfish.....	3

INSECTS

<i>Blabera</i> sp.....	Giant cockroach.....	100
<i>Enyaliopsis petersi</i>	African giant cricket.....	3

MOLLUSKS

<i>Achatina achatina</i>	Giant land snail.....	3
<i>Achatina fulica</i>	Zanzibar-Madagascar snail....	1

Respectfully submitted.

W. M. MANN, *Director*.

Dr. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 8

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the operations of the Astrophysical Observatory for the fiscal year ended June 30, 1950:

The Astrophysical Observatory has continued its two divisions, the Division of Astrophysical Research, devoted to the study of solar radiation, and the Division of Radiation and Organisms, founded in 1929 for the study of radiation effects on organisms.

Beginning September 1, 1948, the Division of Radiation and Organisms was entirely reorganized under the new chief of the division, Dr. Robert B. Withrow. During this fiscal year Dr. Withrow's extensive program of remodeling and reconditioning the laboratories was completed and his new research program inaugurated.

Progress on the new editions of the Smithsonian Meteorological Tables and the Smithsonian Physical Tables can be reported. The sixth edition of the Meteorological Tables was in press at the end of the year, and the manuscript of the ninth edition of the Physical Tables was nearly completed. This new and completely revised edition of the Physical Tables has been compiled under the direction of Dr. William E. Forsythe. Preparation of this manuscript has proved a colossal task because of the great volume of new material made available since the eighth revision was issued in 1932.

DIVISION OF ASTROPHYSICAL RESEARCH

Early in June 1950, the Director left Washington on an inspection trip that included both the Montezuma, Chile, and the Table Mountain, Calif., field stations. He spent 16 days in June at the first-named station and 9 days in July at the second. Excellent skies prevailed especially at Montezuma during his stay. Many intercomparisons of instruments were made, as well as direct comparisons with substandard silver-disk pyrheliometer S. I. No. 5, which he carried with him from Washington. Inventories were made at both stations of all nonexpendable equipment on hand. Various phases of the work were discussed in detail with the personnel of the field stations.

The Montezuma field station has now been in continuous operation for 30 years. Throughout this period an average of three determina-

tions of the solar constant was made on each day that skies were sufficiently clear. And throughout this whole period every effort was made to maintain the solar-constant values on the same scale. It seems worth while, therefore, to examine whether in these years of observation there is evidence of a progressive change in total radiation given off by the sun. The following table gives the mean solar constant for three decades:

<i>Period</i>	<i>Total number of solar-constant determinations (Montezuma, Chile)</i>	<i>Mean value of the solar constant</i>
1921-30 (inclusive)-----	5, 820	1. 9431
1931-40 (inclusive)-----	5, 520	1. 9463
1941-48 (inclusive)-----	5, 004	1. 9478

This increase of one-fourth of 1 percent in the radiation emitted by the sun in two decades (1925-44) is of particular significance in view of evidence that has accumulated of climatic changes in various localities over the earth. On the whole, these changes indicate that average temperatures have increased somewhat during the past 100 years, with an accelerated increase during the past several decades. A very interesting discussion of these evidences is given by Prof. Julian Huxley (Natural history in Iceland, *Discovery*, vol. 11, No. 3, March 1950; reprinted in general appendix of this Report, p. 327).

As stated in last year's report, funds have been requested to re-establish a third field station. Clark Mountain, in southern California near the Nevada border, has been chosen as the most satisfactory available location.

Work at Washington.—Statistical studies of, and final corrections for, the observational data from our two field stations (Montezuma, Chile, and Table Mountain, Calif.), were carried on under the supervision of W. H. Hoover, chief of the division. Mr. Hoover also supervised the preparation of instruments and equipment for the solar-constant observations, for special research problems in progress at Table Mountain, and for requests for certain instruments received from other institutions. Of these latter, three silver-disk pyrheliometers, each calibrated against the Observatory's standard pyrheliometer, were furnished at cost during the year, as follows:

1. S. I. No. 82 to Dominion Physical Laboratory, New Zealand.
2. S. I. A. P. O. No. 17 to Observatorio Cagigal, Caracas, Venezuela.
3. S. I. A. P. O. No. 18 to Central Meteorological Institute, Bucharest, Rumania.

In addition, two modified Ångström pyrheliometers and one special water-vapor spectroscope were furnished to the Central Meteorological Institute at Uccle, Belgium.

A summary of silver-disk pyrheliometry, in the form of a revision of Dr. Abbot's paper of 1922 on "The Silver Disk Pyrheliometer,"

was published in⁵ December 1949 (Smithsonian Misc. Coll., vol. 111, No. 14). This paper gives the constants and the present locations of more than 90 pyrliometers that have been constructed and calibrated by the Smithsonian Institution and are now in use in widely scattered parts of the world.

Five progress reports were submitted during the year, summarizing observations and exposures of textiles made under contract with the Office of the Quartermaster General, as mentioned in last year's report. This work was carried on mainly at Montezuma, Chile.

Both Dr. C. G. Abbot, research associate of the Observatory, and Dr. H. Arctowski continued their special studies referred to in last year's report.

Work in the field.—At the two continuously operating field stations (Montezuma, Chile, since 1920, and Table Mountain, Calif., since 1925) observations for the determination of the solar constant were made on all days having sufficiently clear skies. In addition to this work, at Montezuma considerable time and effort were spent to maintain the necessary radiation measurements in the work being done for the Quartermaster, mentioned above. These measurements were hampered by a lack of sufficient electric power. It is hoped soon to install new batteries and an improved generator. Since March 1, 1950, the Montezuma station has also exposed certain textiles and other materials at the request of the National Bureau of Standards.

With the cooperation of General Motors Corp. and under the sponsorship of the Office of the Quartermaster General, Department of the Army, as mentioned in our reports for 1947 and 1948, the Observatory established at Miami, Fla., in November 1947, a temporary observing station, where exposures to the sun and sky were made, both direct and through filters, of certain tent materials. Measurements of radiation received were made, as had been done previously at Camp Lee, Va. In addition, studies were made of the water-vapor absorption and spectral-energy distribution of sunlight at this moist, sea-level location. The equipment of the former field station at Tyrone, N. Mex., was used in these studies. By July 1949 the work at Miami was nearly completed. Early in August 1949, Mr. Hoover supervised the dismantling of this temporary Miami station, and the equipment was transported in two trucks to the Table Mountain, Calif., field station. Here, with the aid of funds generously given by John A. Roebling, a second observing tunnel was prepared, similar to, but somewhat larger than, the regular tunnel in use at this station. The new tunnel is about 100 feet to the west of the old one.

It is now possible, for the first time since the solar-constant program was inaugurated nearly 50 years ago, to make simultaneous, duplicate,

spectrobolometric observations at the two tunnels, each tunnel operating with independent equipment but observing the sun through the same sky. As a preliminary to various special experiments that are contemplated with the new tunnel, there was in progress at the end of the fiscal year a series of duplicate solar-constant observations taken exactly simultaneously. A study of these simultaneous observations will doubtless furnish interesting information concerning the dependability of the instrumental and observational procedures.

DIVISION OF RADIATION AND ORGANISMS

(Report prepared by R. B. WITROW)

The principal activities of the Division of Radiation and Organisms for the first two-thirds of the year were concerned with concluding the reorganization and reconstruction of the laboratory facilities. The division laboratories are now in first-class condition for plant photochemical research and include four constant-condition rooms, as follows:

A 2° C. cold room for chemical isolation and analyses of labile compounds.

A plant-growing room with one large luminaire for the routine production of plant material and eight small compartments for growing plants under controlled conditions of intensity and wavelength.

A monochromator room for action spectrum studies.

A general experimentation room.

A new type of fluorescent-incandescent luminaire has been developed which involves the use of a special type of lamp holder for the fluorescent lamps, making it possible to put thirty-four 8-foot Slim-line lamps in a unit 4 feet wide and 8 feet long. The separation between the tubes is only $\frac{1}{4}$ inch. Behind the lamps is a bank of twelve 60-watt incandescent lamps. These lamps raise the long-wavelength energy level of the unit to permit a better type of growth than is possible with fluorescent lamps alone. The fluorescent lamps operate in series at 450 milliamperes on an 18,000-volt transformer and reactor. This arrangement greatly simplifies wiring and makes it possible to remove all auxiliary equipment from the growing room. The luminaire has a glass window and an exhaust system, making it possible to operate with a power input of 4 kilowatts without excessive heating. With this luminaire it is possible to obtain 2,500 foot-candles 2 feet below the unit. This is nearly double the intensity possible with similar luminaires designed around conventional auxiliaries and standard lamp holders.

A self-condensing type of water-cooled incandescent lamp luminaire has been developed which condenses the water vapor from the water-

filter cell and makes it possible to operate a unit involving one or more internal reflector lamps without contamination of the distilled-water filter by dust in the air or replacement of it for at least 2 weeks of continuous operation. This type of unit is proving useful for the incandescent irradiation of small cultures of algae and germinating seedlings. With this luminaire it is possible to obtain 3,000 foot-candles over small areas without excessive temperature rise of the irradiated cultures.

Two large grating monochromators have been designed and are now being constructed for action spectrum studies. One unit will be used for recording absorption spectra and the other as an irradiation monochromator for action spectrum studies. The source for the irradiation monochromator is a 12-kilowatt carbon arc.

A new type of 60-cycle conductance bridge with a phase-detector amplifier has been developed which records directly changes in conductance of $1/R$ instead of some complex function of resistance, as with conventional bridges. With this instrument it is possible to follow changes in the concentration of dilute inorganic nutrient solutions with a precision of better than 0.3 percent, and no replotting of data is necessary. Continuous recordings of the uptake of single salts by seedlings may be followed, as well as the loss of salts from roots and other tissues. This instrument is being used for studies of the effect of light and growth substances on ion exchange in plant tissues.

During the latter third of the year experimental work was under way in three general areas: First, the effect of native and synthetic auxins on the water and ion exchange relations of potato-tuber tissue and corn and bean roots. As this work is being supported by the United States Army Chemical Corps, the results are not available for this report. The second area of work pertains to an investigation of the action spectrum and pigment systems involved in photomorphogenesis of seedlings. Seedlings are being grown under conditions of constant light intensity and limited spectral range as obtained by large dyed gelatin filters prepared in these laboratories in order to separate photomorphogenesis from the other photochemical reactions of phototropism, chlorophyll synthesis, and photosynthesis. The third area of investigation pertains to the effect of light on the permeability of plant tissues and on the capacity of seedlings to absorb nutrients from single salt solutions. These data are being obtained by continuous recording of solution conductance.

A paper entitled "Light as a Modifying Influence on the Mineral Nutrition of Plants" was presented by the chief of the division at the Symposia on Plant Growth Substances and Mineral Nutrition of Plants at the University of Wisconsin in September 1949.

The work of the division was materially aided by a generous grant last year by the Research Corporation for basic equipment and facilities. This support is gratefully acknowledged and has been invaluable to the reorganization program.

Respectfully submitted.

L. B. ALDRICH, *Director.*

DR. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 9

REPORT ON THE NATIONAL AIR MUSEUM

SIR: I have the honor to submit the following report on the activities of the National Air Museum for the fiscal year ended June 30, 1950:

HIGHLIGHTS

The National Air Museum suffered a great loss in the death in January of General of the Air Force H. H. Arnold, whose interest in the establishment of an aeronautical museum for the Nation was of long standing. Following the close of World War II General Arnold contributed generously both time and effort in the movement before Congress to make the museum a reality, and after its establishment in 1946 he continued, through correspondence and personal contacts, to help the new agency. At its meeting on May 24, 1950, the Advisory Board of the National Air Museum unanimously adopted the following resolution:

WHEREAS, The May 24 meeting of the Advisory Board of the National Air Museum is the first since the lamented death on January 15, 1950, of General of the Air Force H. H. Arnold; and

WHEREAS, It was General Arnold who developed the idea of a National Air Museum to memorialize the national development of aviation, and to preserve for posterity aeronautical material of historic interest and significance; and who, moreover, ordered the setting aside of examples of aircraft and aviation materials used or developed during World War II for future preservation:

Therefore be it

Resolved, That the Advisory Board of the National Air Museum records in its minutes its profound sorrow and its deep sense of loss in the death of General Arnold, brilliant leader and man of vision and foresight; and be it further

Resolved, That a copy of this resolution be sent to the family of General Arnold and to the Secretary of the Air Force.

On March 17, 1950, the report to Congress on the National Air Museum, required by law, was submitted to the President of the Senate and the Speaker of the House of Representatives, respectively. This report carries out the stipulation of section 3 of Public Law 722, establishing the National Air Museum, that the Secretary of the Smithsonian Institution shall submit "recommendations to Congress for the acquisition of suitable lands and buildings for said national air museum."

On June 1, 1950, the services of Maj. Gen. Grandison Gardner as the United States Air Force representative on the Advisory Board were terminated by reason of his transfer to a post of duty away from Washington. General Gardner's enthusiastic interest and advice on Air Museum matters during his year's tenure in this office were most helpful to the Board and the Air Museum staff. In his stead, Gen. Hoyt S. Vandenberg, Chief of Staff, United States Air Force, appointed Lt. Gen. K. B. Wolfe as his representative on the Board.

The Air Museum had so busy a year that backlogs developed in several of the bureau's work programs. Requests for information were of large volume, and a quarter of the curator's time was spent on this service in addition to considerable time of two associate curators. There were accessioned and cataloged 465 items—a four-fold increase over last year—and there were designed, prepared, and installed three times as many temporary special exhibits of current or commemorative significance as the year before.

Worth-while improvements were made, too, in the bureau's condition and operations. At the Park Ridge storage facility, for example, a considerable portion of the space originally rented by the bureau was vacated, and the smaller retained area was enclosed by fencing. These changes permitted the safe reduction of the watch force from 10 to 7 guards and the employment, at no increase in over-all cost, of additional technical and clerical help to further the essential preservation and accessioning programs. With the help of a second museum aide added to the Washington staff, marked improvements were made in the aeronautical exhibits.

MUSEUM BUILDING STUDIES

As indicated in the bureau's recent annual reports, for the past 2 years studies have been conducted by the bureau's staff in cooperation with the Public Buildings Administration to determine a suitable Museum building and site. After 17 months of work these studies were completed, and a report thereon was presented to the Advisory Board on June 29, 1949.

The report embodies the ideas of the Advisory Board members, of architects and engineers of the Public Buildings Administration, and of the professional staff of the bureau regarding the scope and volume of the proposed aeronautical collection and the equipment, facilities, and services required to maintain, exhibit, and preserve the collection and operate the Museum. The descriptive matter, perspective drawings, preliminary floor plans, estimates of costs, and suggestions of suitable sites contained in the report are believed to provide a

basic scheme from which there can be developed a feasible and adequate building for the national aeronautical collections.

With this report as a nucleus, the required report to Congress was prepared this year and, as indicated earlier, was submitted to Congress on March 17, 1950.

ADVISORY BOARD

A meeting of the Advisory Board of the National Air Museum was held on May 24, 1950, with the following members present:

Dr. Alexander Wetmore, chairman, Secretary of the Smithsonian Institution; Rear Adm. A. M. Pride, Chief, Bureau of Aeronautics, Department of the Navy; Maj. Gen. Grandison Gardner, Deputy Chief of Staff, Matériel, Department of the Air Force; Grover Loening, Presidential appointee; William B. Stout, Presidential appointee.

The death of Gen. H. H. Arnold, who was known personally by all members, was the subject of a commemorative conversation among the members and resulted in the resolution mentioned in the fore part of this report. The Board then heard brief reports by staff members on the year's operations by the bureau at the Park Ridge, Ill., storage facility and in the conduct of the Museum activities in Washington. These operations are described under separate headings in subsequent parts of this report. In connection with the storage operations, the Board approved the staff's list of aeronautical items in the collection that are to be rejected as unnecessary to the Museum.

With the knowledge that the required report to Congress on the National Air Museum was in the hands of that body, the Board gave considerable attention to the problems involved in advancing the Air Museum's site-procurement and building programs. It was appreciated that positive action must await, as with all federally supported building programs, specific authorization by Congress.

SPECIAL EVENTS

During the year the Air Museum participated both as host and guest in a number of unusual events connected with the acquisition of new aeronautical items for the national collection. The following are worthy of mention:

On July 3, 1949, during the Air Force Association's annual convention in Chicago, and as one of the public events held at the O'Hare International Airport, there was received for the Museum the United States Air Force B-29 superfort *Enola Gay*, famous as the first aircraft to drop an atomic bomb in warfare. The presentation was made by Maj. Gen. Emmett R. O'Donnell, Jr., Commanding General of the 15th Air Force, with Col. Paul W. Tibbets, pilot of the *Enola Gay*,

and Maj. Thomas W. Ferebee, bombardier, in attendance. C. W. Mitman, Assistant to the Secretary for the National Air Museum, accepted it for the Museum. The previous day at the Air Force Association annual convention luncheon, the Air Museum was awarded a bronze plaque and citation in recognition of its continuing interest in and devotion to the Nation's aeronautical history. The award was made by Gen. James Doolittle, United States Air Force (Ret.).

On July 7, 1949, at the Washington National Airport, there was formally presented to the Museum the Stinson SR-10F airplane that had been used by All American Aviation in airmail pick-up service and later was employed by the Air Force in developing the techniques of picking up airplanes, gliders, and persons from the ground. Norman Rintoul, the donor, who had piloted this plane in the above operations, demonstrated these methods prior to the presentation.

On September 8, 1949, at the airport, the *City of Washington*, Piper Super Cruiser that had been flown around the world in 1947 by Clifford Evans, Jr., was presented by William T. Piper. It was flown in for the presentation by George Truman, who had accompanied Evans on the world flight in a similar airplane.

On October 7, 1949, at a small but impressive presentation ceremony in the Aircraft Building in Washington, memorabilia of the internationally famous aviatrix Amelia Earhart, consisting of a portrait sculpture, flight maps, globe, books, radio, photographs, models, trophy, and medals, were presented to the Air Museum by the Amelia Earhart Post of the American Legion, Department of California. Mrs. Amy Otis Earhart, mother of the aviatrix, unveiled the exhibit.

On November 8, 1949, the Museum received from Power Jets, Ltd., London, England, the original Whittle W-1-X turbojet engine in a presentation ceremony, held in the auditorium of the United States National Museum, in which several of the Advisory Board members participated. The presentation was made by the British Ambassador, and addresses were made by W. E. P. Johnson, Managing Director of Power Jets, and Sir Frank Whittle, the inventor of the engine, both of whom journeyed from London, England, for the occasion. The acceptance address was made by Dr. A. Wetmore, Secretary of the Smithsonian Institution.

On January 27, 1950, in the Regents' Room of the Smithsonian, in the presence of several Board members, Mr. and Mrs. Elmer F. Wieboldt, of North Garden, Va., presented a bronze bust of Wilbur Wright by the sculptor Oskar J. W. Hansen. With this accession, the Museum now has bronze busts of both Orville and Wilbur Wright by the same sculptor. They are appropriately exhibited in the Aircraft Building.

Lastly, on June 28, 1950, the Air Museum participated as host to a small company gathered in the Aircraft Building to witness the awarding of a citation to Mrs. ("Mother") C. A. Tusch, Berkeley, Calif., by the United States Air Force, in recognition of her great interest in and fostering of airmen over the past 30 years. In the course of her long voluntary service Mrs. Tusch had gathered in her home a large collection of aeronautical memorabilia which she generously presented to the National Air Museum earlier in the year. A token exhibit of the "Mother" Tusch collection formed the background for the ceremony setting.

CURATORIAL ACTIVITIES

The curator, Paul E. Garber, reports on the year's work as follows:

The general condition of aeronautical exhibits continues good, but the need for space is desperate. Until an adequate building of its own is provided, the National Air Museum is restricted for its displays to the Aircraft Building—a World War I hangar erected in 1919—and a small hall and overhead suspended exhibits in the adjacent Arts and Industries Building. These areas now house 37 man-carrying aircraft together with numerous engines, structural parts, and cased displays of parachutes, instruments, flight clothing, models, and other material reflecting some of the accomplishments of designers, engineers, and airmen. Were adequate space available a far more complete picture of aeronautical progress could be created with the irreplaceable material that the Museum now has in storage. This is a source of much disappointment to the visitor, the student, and historians.

A number of improvements were made in the bureau's exhibits during the year. Two bays in the Aircraft Building are now assigned to the Wright Brothers. In one, the portrait busts of Wilbur and Orville Wright are associated with memorials and awards; in the other there is displayed a reproduction of their wind tunnel, while on the walls their story is augmented by photographs, drawings, and paintings. To satisfy further the public interest in the *Kitty Hawk*, a 4-panel floor frame containing photographs of the Wright Brothers, a picture of their first flight, and a nomenclature drawing of the machine was installed beneath the plane. Twelve scale models of aircraft, illustrating types developed and flown by a number of the pioneers who followed the Wright Brothers, were attractively arranged in realistic action positions in a scenic setting depicting a flying field of the pioneer period. The planes are identified in the text on a miniature "billboard" bordering the field. A splendid series of paintings by Jerome D. Biederman, illustrating World War II air-

craft in service, were utilized to augment an older display of scale models of these planes. Among other exhibits improved were the Thompson Trophy series and the story of the first American air force—the balloon corps established during the Civil War. With the help of Col. Roderick Tower, who had once been a pilot of the Curtiss *Jenny* now in the collection, the original numbering and insignia of this airplane of World War I were restored, thereby improving the appearance and authenticity of the plane. Numerous other exhibits were serviced; the cleaning and repairing of all aircraft maintained; and the continuing project to provide accurate drawings and a representative space control scale model for each aircraft in the collection was advanced.

Among new accessions of aircraft and engines, the *Enola Gay* and Whittle W-1-X are outstanding. Of the 14 full-sized aircraft accessioned, only one, the Roadable Autogiro, could be given exhibition in Washington; all the others were placed in the storage area. Five engines were received during the year, three being jets. In deference to the increasing size of huge bombers, transports, and patrol planes, a departure from the Museum standard airplane model scale of 1:16 was decided upon, and 1:48 adopted for the larger models. Two of this new scale, a Northrop flying wing B-49 and a Fairchild cargo plane C-82, were added to the collection. A large sectioned model, 1:8, of the Piasecki helicopter permits technical study of this type. One guided missile, a Navy "Bat," was acquired, and enables the Museum to show the contrast between a radio-guided weapon and the human-guided "suicide" Japanese Baka bomb previously accessioned.

In addition to the aeronautical material actually accessioned this year, it can be reported that the Department of the Navy has placed in safe storage for the Museum the Lockheed P2V *Truculent Turtle*, which established the present long-distance, nonstop, nonrefueled flight record, and the Vought F-5-U. The F-5-U is a unique development of low aspect-ratio wing configuration which has an unusually wide range of flight performance.

Projects under way at the close of the year included a rearrangement of the aircraft engine collection in the Aircraft Building; improving, through the use of an automatic slide projector, the illustrated story of Colonel Lindbergh's flights in the *Spirit of St. Louis*; and preparing a commemorative display to record the fortieth anniversary of the beginning of carrier operations in the Navy.

STORAGE

Compression of material to conserve space, development of preservation techniques, disassembly of aircraft, and packing of aeronautical

materials have been the four principal categories of work at the Museum's storage facility at Park Ridge, Ill., this year.

Following an intensive period of preplanning, the curator, with the help of the storage facility staff and two of the staff from Washington, concentrated the entire stored collection within about one-half of the space previously occupied. This was followed by the erection of an 8-foot-high wire-mesh fence enclosing the entire area, the fence being so made that individual panels are removable to facilitate the movement of aircraft into and out of the area.

Preservation of aircraft flown in requires running up of the engines and giving them protective coatings while they are free and warm, draining tanks and venting fumes, cleaning the aircraft inside and out, placing dehydrators, and sealing all openings with tape. Proper treatment of material, when received, requires cleaning, inspecting, and replacing of preservatives. A large backlog exists in the inspection and preservation of the aeronautical items originally transferred to the bureau by the Air Force. As an example of the work involved in preservation, the cleaning of the propellers on the *Enola Gay*, which, prior to its transfer to the Air Museum, had been stored outdoors for a long period, required 247 man-hours of time. Another rust-removing project involving the cleaning and applying of preservatives to the *Enola Gay's* engines will consume an estimated 1,400 man-hours.

The disassembly of aircraft condenses the space they occupy, and this task constitutes the initial step taken toward boxing them. Some of the planes received from the Air Force had been partially dismantled and required further disassembly. Including these and the aircraft dismantled entirely by the facility personnel, 59 were handled during the fiscal year involving 1,697 man-hours.

The boxing program is intended, as far as is practical, to prepare all stored material for safe storage and future shipment to Washington. Twenty-nine aircraft, 67 engines, and other aeronautical materials were already packed in boxes when received from the Air Force. The boxes had become damaged, however, through repeated handling, and many of them were repaired during the year. In addition, 6 airplanes were packed, requiring 18 boxes and consuming 950 man-hours. Economies were effected by extensive salvaging of lumber from the boxes and crates in which rejected aircraft had been placed. Most of the aircraft and material received during the fiscal year were delivered in permanent boxes.

These several major continuing projects begun during the year required nearly a fifth of the curator's time in planning and supervision. Several conferences of Air Force, Navy, and Air Museum

personnel had to be held—for example, to develop standards for retention or rejection of material for Museum purposes. There was involved, too, the details of the design and procurement of a large variety of essential equipment and supplies to carry on the work.

INFORMATIONAL SERVICES

To satisfy the demand for the bureau's informational services, there was required during the year the expenditure of the equivalent of over 2 man-years of the staff's time. Some examples of this great volume of requests received are:

The National Defense Establishment was assisted by the loan of models of the Navy PBV and Air Force B-25 airplanes which served as the basis for larger models to be used for electronic evaluation tests. The Court of Claims was aided in its investigation of the origin of radio-shielding on aircraft engines. A number of photographs preserved by the Archives were given correct identification. The commemorative stamp issued on the forty-sixth anniversary of the Wright Brothers' first flight and the first anniversary of the return to America of the *Kitty Hawk*, was checked for design, accuracy of technical detail, and text by the staff, working with officials of the Post Office Department and the Bureau of Engraving.

The aeronautics classes of the District of Columbia high schools were supplied with a list of nonmilitary uses of aircraft compiled for their information and discussion. The Aircraft Industries Association was given facts regarding the Wrights' first engine for use in a research project. The curator served on the committee of the National Aeronautic Association which determined the annual awardee for the Brewer Trophy. Many hobbyist modelmakers were assisted with loans of drawings and photographs, and photographic collectors exchanged prints with the Museum to mutual advantage. The Handbook of the National Aircraft Collection, written by the curator, continues to be in great demand, and the ninth edition will shortly be undertaken. The United Service Organization ordered this year a large number of copies for its libraries, and many schools continue to use it as a text.

The bureau continued, as in former years, to satisfy as far as possible the requests of District of Columbia citizens' groups for illustrated lectures on aviation subjects.

SURVEY

Concentration by the staff on operations at the Washington base, and at the field storage facility limited the time available for survey

trips to locate and examine new material. The following surveys were made:

Dearborn, Mich., January 18, by the curator and Stephen Beers, associate curator, to inspect aeronautical material at the Edison Institute.

Dayton, Ohio, March 25, by Robert Strobell, associate curator, to inspect Air Force and other material available to the museum.

ACCESSIONS

This year the bureau received 34 new accessions from 31 sources totaling 465 specimens. Each accession was fully recorded in the Museum's catalog system and formally acknowledged. The list follows:

AIR FORCE, DEPARTMENT OF, Washington, D. C.: The Boeing B-29 superfortress bomber *Enola Gay* used to drop the first atomic bomb in warfare, on Hiroshima, Japan, August 6, 1945 (N. A. M. 682).

AMELIA EARHART POST 678, AMERICAN LEGION, DEPARTMENT OF CALIFORNIA, Los Angeles, Calif.: A collection of 6 objects associated with the aeronautical accomplishments of the late Amelia Earhart: the globe on which she planned her flights (contributed by Mrs. Amy Otis Earhart); a sculptured portrait (contributed by Mrs. Grace Wells Parkinson, the sculptress); the radio used on her Atlantic flight (contributed by Paul Mantz); two scale models of Lockheed Vega and Electra airplanes which she flew, and a trophy intended to be presented at conclusion of the world flight (contributed by the Lockheed Aircraft Corporation) (N. A. M. 689).

BEECH AIRCRAFT CORP., Wichita, Kans.: The Beech Bonanza airplane *Waikiki Beech* in which the late Capt. William P. Odom set a world's nonstop, straight-line, distance record for light planes of 4,957.24 miles from Honolulu, Hawaii, to Teterboro, N. J., in 36.23 hours, March 7-8, 1949 (N. A. M. 667).

BIEDERMAN, JEROME D., San Francisco, Calif.: 59 full color paintings of United States, British, German, and Japanese warplanes in use during World War II (N. A. M. 660, loan).

CIVIL AERONAUTICS ADMINISTRATION, Washington, D. C.: A Pitcairn Roadable Autogiro, significant as an early and successful attempt, under Government sponsorship, to provide a practical, low-cost, road/air vehicle for private pilots (N. A. M. 672).

ELEY, MAJ. J. S. M., Alexandria, Va.: Eight insignia cut from sides of World War I airplanes; a French barometric altimeter taken from a French plane, World War I; and two name plates, one a Caproni, the other a Mercedes, from World War I equipment (N. A. M. 658).

FAIRCHILD ENGINE AND AIRPLANE CORP., Hagerstown, Md.: A 1:48-sized scale model of a Fairchild C-82 "Packet," the first military cargo and troop transport designed as such (N. A. M. 664).

FRACKELTON, MR. AND MRS. ROBERT, Fredericksburg, Va., "In Memory of 1st Lt. Rollin N. Conwell, Jr., USMCR": A bronze, life-size portrait bust of Orville Wright made from life in 1931 by Oskar J. W. Hansen (N. A. M. 670).

GOODYEAR AIRCRAFT CORP., Akron, Ohio: An exhibit illustrating the cross-wind landing-wheel design developed by the donor under Civil Aeronautics Administration sponsorship (N. A. M. 657).

GRANT-SMITH, HON. U., Washington, D. C.: A flechette (steel dart), air-ground, antipersonnel weapon of World War I (N. A. M. 679).

- GUGGENHEIM FOUNDATION, THE DANIEL AND FLORENCE, New York, N. Y.: The Robert H. Goddard Rocket Exhibit totaling 29 specimens consisting of 1 large and 1 intermediate rocket and a significant selection of units with descriptive charts (N. A. M. 668).
- KIRK, HARRY E., St. Louis, Mo.: A Consolidated PT-1, U. S. Army training plane, the first of the "modern" United States military primary trainers (N. A. M. 676, loan).
- KIRK, PRESTON, St. Louis, Mo.: An SE-5A airplane, an example of a single-seat British fighter used by Great Britain and United States during World War I. This particular specimen was one of 50 assembled in the United States for the Army, 1922-23 (N. A. M. 677, loan).
- KORN, DR. EDWARD A., East Orange, N. J.: A photograph album containing 98 prints showing scenes from the early flying activities of Edward Korn and his late brother Milton, 1908-15, as well as pictures of other "Early Bird" airplanes (N. A. M. 665).
- KORN, DR. EDWARD A., East Orange, N. J., and KORN, ARLINGTON L., Jackson Center, Ohio: A Benoist tractor biplane of 1911, one of the earliest planes of this type (N. A. M. 666).
- LEE, CAPT. E. HAMILTON, Glendale, Calif.: A United Air Lines pilot's uniform worn by donor prior to his retirement as senior pilot of United, July 1949 (N. A. M. 673).
- LOENING, ALBERT P., Southampton, N. Y.: A 1:16-sized scale model of the Loening Air Yacht. This model represents the high-performance 5-place flying-boat design that won the 1921 Wright Efficiency Trophy and the Collier Trophy for its designer, Grover Loening (N. A. M. 675).
- LOS ANGELES, CITY OF, Calif.: The Boeing B-17D *Swoose*; one of the very few combat-type aircraft operational on December 7, 1941, and still in service at the end of World War II (N. A. M. 662).
- MCDONNELL AIRCRAFT CORP., St. Louis, Mo.: Two 1:16-sized scale models of McDonnell aircraft: an FH-1 "Phantom," the U. S. Navy's first operational jet fighter and also the first U. S. all-jet aircraft to land and take off from a carrier; and an F2H "Banshee," carrier-based, single-seat jet fighter (N. A. M. 661).
- NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS, Langley Field, Va.: An N. A. C. A. "Quiet" propeller designed by the donor to reduce noise in light airplanes (N. A. M. 688).
- NAVY, DEPARTMENT OF, BUREAU OF AERONAUTICS, Washington, D. C.: A Westinghouse 19A "Yankee" engine, the first purely American-designed axial-flow turbojet engine (N. A. M. 684); a cutaway Westinghouse 9.5A (J.32) axial-flow turbojet engine designed to Navy specifications for powering guided missiles or small pilotless target aircraft (N. A. M. 685); a "Bat" pilotless glide bomb, radar controlled, the only Allied pilotless missile weapon designed by America or Allies used operationally in World War II (N. A. M. 686); a magnetic compass used on the NC-4 during the first transatlantic flight, 1919 (N. A. M. 687).
- NORTHROP AIRCRAFT, INC., Hawthorne, Calif.: A 1:48-sized scale model of the Northrop B-49, the first jet-propelled flying wing bomber designed and developed by donor for the United States Air Force (N. A. M. 659).
- PIASECKI HELICOPTER CORP., Morton, Pa.: A 1:8-sized scale model of the Piasecki HRP-1 Helicopter *Rescuer*. The first successful tandem rotor transport helicopter design to go into production (N. A. M. 674).

- PIPER AIRCRAFT CORP., Lock Haven, Pa.: A Piper Super Cruiser airplane, *City of Washington*, flown around the world, August 9–December 10, 1947, by Clifford Evans, Jr. (N. A. M. 683).
- POWER JETS, LTD., London, England: The Whittle W-1-X turbojet engine which was the first practical turbojet engine to successfully propel an aircraft in flight; and a 1:24-sized scale model of the Gloster-Whittle E 28/39 "Pioneer" experimental aircraft powered by the foregoing type of engine and representing the first successful turbojet-propelled aircraft (N. A. M. 669).
- RINTOUL, NORMAN, Pittsburgh, Pa.: A Stinson SR-10F "Reliant" 5-place cabin monoplane. Equipment used for mail and human pick-ups is included (N. A. M. 663).
- ROOSEVELT FIELD, INC., Mineola, L. I., N. Y.: Three full-sized airplanes: a Baldwin "Red Devil," 1910–11; a Bleriot XI, 1914; a Nieuport 12, 1917–18; and 2 aircraft engines: a Curtiss V-4 and a Salmson Z-9 of World War I period (N. A. M. 680).
- TUSCH, MRS. C. A. ("Mother"), Berkeley, Calif.: The collection of aeronautical memorabilia acquired by the donor from World War I to 1950 and formerly exhibited in her home, known as "The Hangar, Shrine of the Air." The collection of 325 listings consists of propellers, aeronautical and military uniform emblems and insignia, flight clothing, parts of aircraft and engines, personal souvenir items, wallpaper panels with original signatures, and framed photographs, many of which are autographed (N. A. M. 690).
- WATERMAN, WALDO, Santa Monica, Calif.: The Waterman *Whatsit* airplane of 1932, an early design of a tailless monoplane (N. A. M. 681).
- WHITNEY, GEORGE K., San Francisco, Calif.: An "Albatros" D-5 airplane of World War I, a type used widely by the German Air Force (N. A. M. 678).
- WIEBOLDT, MR. AND MRS. ELMER F., North Garden, Va.: A bronze, life-sized portrait bust of Wilbur Wright sculptured by Oskar J. W. Hansen in 1949 (N. A. M. 671).

Respectfully submitted.

CARL W. MITMAN,

Assistant to the Secretary for the National Air Museum.

DR. A. WETMORE,

Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON THE CANAL ZONE BIOLOGICAL AREA

SIR: It gives me pleasure to present herewith the annual report of the Canal Zone Biological Area for the fiscal year ended June 30, 1950.

IMPROVEMENTS MADE

A reinforced-concrete 11,720-gallon water tank, for ordinary uses as well as for fire protection, was built about 400 feet from the start of the Snyder-Molino Trail. The elevation of the tank above the laboratory level is such as to furnish enough pressure to bring the water over the roof of the large main building. The 4,000-gallon concrete water tank built in 1948 is now being used only for rain water for drinking and laboratory needs.

The land south of the Chapman house was leveled in preparation for the reconstruction of the building used for corrosion and deterioration tests; and the material necessary for a 12-foot extension to this building was purchased. The present house, originally built in 1926, is infested with termites. Considerable progress was made in clearing the land back of the present laboratory group to allow space for more effective separation of our buildings to eliminate fire hazard.

The floating equipment is in good shape. A reduction gear was added to the launch *Luna*. The narrow-gage rail line from the Frijoles dock to the railroad station was relocated and improved.

SCIENTISTS AND THEIR STUDIES

During the year, 21 scientists made use of the island's facilities. Present costs of transportation are keeping many from coming, and for the same reason a number of those who come do not stay as long as they would like to. Since the laboratory was started in 1923, about 660 separate papers relating to work done at Barro Colorado Island have appeared in print, not including the many reports made by representatives of Government agencies.

Dr. Alfred O. Gross, professor of biology, Bowdoin College, accompanied by Mrs. Gross, returned to the island after an absence of 25 years, to continue his studies of birds. He spent about 6 weeks studying in great detail and photographing the Hicks's seedeater and the little flycatcher, *Myiobius barbatus*, and made valuable observations of many other species. The island is exceptionally well suited for the investigation of the birds of the lower tropical forest.

Dr. Robert Zanes Brown, of Johns Hopkins University, spent 6 weeks on the island, accompanied by Mrs. Brown as assistant. His main objectives were to obtain additional ecological data on army ants for Dr. T. C. Schneirla, of the American Museum of Natural History, and to locate and check up on the 18 queens of *Eciton hamatum* and 9 of *E. burchelli* that he marked and left with their colonies in the 1948 dry season. He not only found the marked queens but was able to follow their movements day by day. Dr. Brown is also interested in mammalian ecology, and, having the opportunity to see more of the island and its life than he was able to during his 1948 visit, he made valuable observations on population numbers and behavior.

Dr. A. M. Chickering, of Albion College, Albion, Mich., returned to continue his exhaustive studies on the spiders of the island, Canal Zone, and Panamá. This is his fifth visit. He has published 15 papers on spiders of the region, the one on the salticids alone numbering 474 pages. His estimate of the number of species of spiders on Barro Colorado Island is 1,200.

Dr. Per Host, of Norway, returned to the island to continue his studies of the birds and mammals, as well as the general forest. With his special photographic equipment he made additional motion pictures and stills, in black-and-white and color. He also made many wire sound recordings of the voices of the jungle. In addition to his island studies, he revisited the Chocó Indians of Darién and the Cunas of San Blas and made photographic records and sound recordings of the songs, chants, and language. These records, being the only ones in existence, will become increasingly valuable as the customs and language of these Indians are lost through the encroachments of civilization.

Dr. Eugene Eisenmann, of New York City, continued his study of the birds of the region, with which he is unusually familiar. From the island records he has prepared a list of all the birds known from the island and has added many species to it himself.

Scott Seegers, of McLean, Va., and Mrs. Seegers, spent a few weeks on the island to obtain first-hand information on the plants and animals, and to consult published papers on studies made there, in connection with the preparation of an article.

Dr. Lawrence Kilham, Microbiological Institute, Laboratory of Infectious Diseases, National Institutes of Health, spent 4 days on the island, primarily to study the birds, and subsequently the mammals. His 12-page report is replete with careful observations and comparisons with conditions and the biota of Northeast Greenland. The number of birds he saw on the island was far beyond his expectation. Of the mammals he records howler monkeys (infested with

bot flies), white-faced capuchins, coati-mundis, peccaries, tamanduas, tayras at close range, tapirs, ñequis, and sloths.

G. W. Cottrell, of the Harvard University Library, and Mrs. Cottrell, spent about 2 weeks on the island to observe the whole complex of plant and animal life in a tropical rain forest. Their main interest was the study of the bird life, and, to a lesser degree, Lepidoptera. They covered fully half of the island's trails and had opportunity to study and observe the abundant mammalian life. Of birds, they identified 115 forms, 2 of which were new to the records of the island. Also they made a representative collection of Lepidoptera and took many photographs.

Mrs. E. R. Kalmbach, of Denver, Colo., was able to spend 3 days on the island, after a longer stay in Colombia. Her special interests were the flora and the birds, and to a lesser extent the mammals.

Ken Stott, Jr., general curator of the Zoological Society of San Diego, Calif., accompanied by Mrs. Stott, spent about 10 days on the island gathering first-hand knowledge of birds and mammals in the wild state in order to modify and improve the present exhibit and maintenance of the animals in the San Diego Zoo. He found opportunities for observing American tropical rain-forest wildlife on Barro Colorado Island to be unparalleled from the viewpoint of a zoo naturalist. During his brief stay he observed 102 species of birds and 11 of mammals, among the latter the ocelot and tapir. Special attention was given to feeding habits, particularly the manner of feeding and the types of food preferred, especially by the three species of diurnal primates, the tamandua anteater, the three-toed and two-toed sloths, and a number of birds, most of which are difficult to maintain in captivity for any great length of time.

Dr. Rolf Blomberg, of Norway, spent 2 weeks on the island collecting material for his forthcoming book on the fauna of tropical America. In his report he refers to the richness of the island fauna, to the great helpfulness of the library facilities, and states that in no other part of the world has he been able to carry out such studies with greater ease and under pleasanter circumstances.

Dr. Frederick W. Loetscher, Jr., of Centre College, Danville, Ky., with Mrs. Loetscher, spent 2 weeks on the island, mainly to study birds. A keen observer, he left with the laboratory a detailed list of the 102 species he definitely identified, with notes on their abundance. In addition, he made observations on the primates and edentates. Such reports, accumulated over long periods, give a valuable index to trends in populations, particularly relative abundance.

Dr. H. B. Goodrich, professor of biology of Wesleyan University, Middletown, Conn., spent 4 days on the island observing and

"experiencing" a tropical rain forest for the purpose of providing a biological background for his teaching. He also took many color photographs.

Dr. Cleveland Soper, director of the Tropical Research Laboratory of Eastman Kodak Co., continued exposure tests throughout the year, assisted by Paul Hermle, physicist, George Ade, chemist, and Ismael Olivares, microbiologist. These tests have yielded very valuable results, and, in Dr. Soper's opinion, the test tables for the island are the most practical way to determine the effectiveness of biocides in preventing deterioration of processed photographic materials, as well as the resistance of various protective coatings to tropical climatic conditions, etc. The correlations obtained between samples at the test table and similar items in actual use are more than satisfactory. Several important publications have resulted from these studies, such as "Notes on Tropical Photography," "Care of Films and Cameras in Tropical Climates," "Prevention and Removal of Fungus Growth on Processed Photographic Film," and "Notes for the Photo-Traveler." The prevention of corrosion of lenses by fungi is one of the important projects. These exposure tests emphasize the value of rapid and long-term studies of the effects of temperature and humidity, especially as they pertain to fungus growth. The island is particularly well suited for studies of corrosion and deterioration and the evaluation of biocides under such severe climatic conditions.

W. E. Lundy, of the Panama Canal and secretary-treasurer of the Panama Canal Natural History Society, again spent about a week on the island studying the birds and mammals, and particularly the "voices" of the jungle. His observations are of special interest because they help to give a better idea of faunal abundance and fluctuation in numbers.

Jay A. Weber, of Miami, Fla., spent considerable time in Panamá, part of it on the island, collecting mollusks, of which there is a superabundance of species. He was interested mainly in gathering the fresh-water and land forms of the island, largely for the United States National Museum. His previous visit to the island, to study birds, was 22 years ago.

Dr. Alexander Wetmore, Secretary of the Smithsonian Institution, revisited the island and held conferences with the resident manager on plans for the future of the area and proposed improvements. W. M. Perrygo, of the National Museum, accompanied him.

John E. Graf, Assistant Secretary, Smithsonian Institution, spent a few days on the island examining the laboratory facilities and the improvements made since his official visit the year before and discussing operations, plans for further improvements, and expansion.

George O. Lee, professor of biology, Junior College, Canal Zone, again brought his students for an overnight stay on the island, as part of their school work. Similar groups from the Normal School of Santiago, Panamá, the Abel Bravo Institute in Colón, and the National Institute of Panamá likewise came to the island.

The resident manager continued his special research problems, particularly the long-term termite-resistance tests, and host relationships of the fruit-fly population. The termite-resistance tests, started in 1924, are of increasing importance each year. During these 25 years 42 detailed reports have been prepared and 48 papers published, largely by Snyder, Hunt, and Zetek. It is possible now to build in the Tropics with untreated timbers despite the abundance of termites, and, with a minimum of vigilance, avoid the ravages of these pests.

Tests were also made on a number of electric-wire insulations, some untreated, others treated with pesticides and fungicides. The many instances in which termites have eaten through lead sheathing, as well as glass wool, prove the importance of these tests.

The Bureau of Entomology and Plant Quarantine continued to explore the worth and usefulness of soil poisons as deterrents to both termites and rot.

The large Berlese funnel was kept in operation and yielded an abundance of rare insects and mites difficult to collect otherwise.

URGENT NEEDS

A steady flow of electric current 24 hours a day is indispensable to a laboratory. The island's present supply of current is manufactured by gasoline-driven generators, some of which are not dependable. Some are single-phase, others three-phase, and this has made it necessary to revamp the entire distribution system. A double-throw three-pole switch had to be installed to separate the various phases and make mistakes impossible when the various generators are used. The drop in voltage at times is considerable. Also the gasoline and oil consumption of the present generators makes electricity too expensive. The only practical solution is to tap the transmission line of the Panama Canal at Frijoles, put in transformers there and on the island, and lay a cable along the lake bottom. This would give a dependable 24-hour daily service at a moderate cost.

LIST OF THE VERTEBRATES OF THE ISLAND (BIRDS EXCLUDED)

The following list, brought up to date by members of the scientific staff of the National Museum, shows a total of 173 species and subspecies of vertebrates (exclusive of the birds) now inhabiting Barro Colorado Island. The card index kept on the island gives pertinent

data as to who collected and identified each species, where and why they were collected, notes on abundance, and the synonymy as it affects previously published data.

FISHES (22)

Pimelodidae:

Rhamdia wagneri (Günther).

Characidae:

Astyanax ruberrimus Eigenmann.

Brycon chagrensis (Kner).

Bryconamericus emperador (Eigenmann and Ogle).

Compsura gorgonae (Evermann and Goldsborough).

Gephyrocharax atricaudata (Meek and Hildebrand).

Hoplias microlepis (Günther).

Piabucina panamensis Gill.

Roeboides guatemalensis (Günther).

Synbranchidae:

Synbranchus marmoratus Bloch.

Poeciliidae:

Brachyrhaphis cascajalensis (Meek and Hildebrand).

Brachyrhaphis episcopi (Steindachner).

Gambusia nicaraguensis Günther.

Molliensia sphenops (Cuvier and Valenciennes)

Cyprinodontidae:

Rivulus brunneus Meek and Hildebrand.

Atherinidae:

Thyrinops chagresi (Meek and Hildebrand).

Centropomidae:

Centropomus parallelus Poey.

Cichlidae:

Aequidens coeruleopunctatus (Kner and Steindachner).

Syngnathidae:

Oostethus lineatus (Kaup).

Gobiidae:

Gobiomorus dormitor Lacépède.

Gobiomorus maculatus (Günther).

Leptophilypnus fluviatilis Meek and Hildebrand.

REPTILES (62)

TESTUDINATA

Chelydra acutirostris Peters.

Geoemyda annulata Gray.

Geoemyda punctariola funerea (Cope).

Kinosternon postinguinale Cope.

Pseudemys ornata Gray.

CROCODYLIA

Caiman fuscus (Cope).

Crocodylus acutus Cuvier.

SAURIA

Gekkonidae:

- Gonatodes fuscus* (Hallowell).
Lepidoblepharis sanctae-martae fugax Ruthven.
Sphaerodactylus lineolatus Lichtenstein.
Thecadactylus rapicaudus (Houttuyn).

Iguanidae:

- Anolis lemurinus* Cope.
Anolis capito Peters.
Anolis lionotus Cope.
Anolis pentaprion Cope.
Anolis biporcatus (Wiegmann).
Anolis limifrons Cope.
Anolis frenatus Cope.
Norops auratus (Daudin).
Polychrus gutturosus (Berthold).
Corythophanes cristatus Boie.
Basiliscus basiliscus (Linnaeus).
Iguana iguana iguana (Linnaeus).

Xantusiidae:

- Lepidophyma flavomaculatum* Duméril.

Teiidae:

- Ameiva festiva* Lichtenstein.
Ameiva leptophrys Cope.
Leposoma southi Ruthven and Gaige.

Scincidae:

- Mabuya mabouya mabouya* (Lacépède).

Amphisbaenidae:

- Amphisbaena fuliginosa* Linnaeus.

SERPENTES

Typhlopidae:

- Anomalepis mexicanus* Jan.

Boidae:

- Constrictor constrictor imperator* (Daudin).
Epicrates cenchria maurus Gray.

Colubridae:

- Amastridium veliferum* Cope.
Rhadinaea decorata Günther.
Rhadinaea pachyura fulviceps Cope.
Coniophanes fissidens fissidens (Günther).
Pliocercus euryzonus dimidiatus Cope.
Oxyrhopus petola sebae (Duméril and Bibron).
Xenodon rabdocephalus (Wiedemann).
Siphlophis cervinus geminatus (Duméril and Bibron).
Leimadophis epinephalus epinephalus (Cope).
Enulius flavitorques (Cope).
Enulius sclateri Boulenger.
Dendrophidion percarinatus Cope.
Dryadophis boddaertii alternatus (Bocourt).
Thalerophis richardi occidentalis (Günther).
Oxybelis aeneus (Wagler).

Colubridae—Continued

- Spilotes pullatus pullatus* (Linnaeus).
Pseustes poecilonotus shropshirei (Barbour and Amaral).
Chironius carinatus (Linnaeus).
Chironius fuscus (Linnaeus).
Imantodes gemmistratus (Cope).
Imantodes cenchoa cenchoa (Linnaeus).
Leptodeira rhombifera Günther.
Leptodeira annulata annulata (Linnaeus)
Stenorkhina degenhardti (Berthold).
Tantilla ruficeps (Cope).
Tantilla albiceps Barbour.

Elapidae:

- Micrurus mipartitus* (Duméril and Bibron).
Micrurus nigrocinctus nigrocinctus (Girard).

Crotalidae:

- Bothrops atrox asper* (Garman).
Bothrops schlegelii (Berthold).

AMPHIBIANS (33)

APODA

Caecilia ochrocephala Cope.

CAUDATA

Oedipus complex Dunn.
Oedipus parvipes (Peters).

SALIENTIA

Bufonidae:

- Bufo granulosus* Spix.
Bufo marinus (Linnaeus).
Bufo typhonius alatus (Thomiot).
Engystomops pustulosus (Cope).
Leptodactylus bolivianus Boulenger.
Leptodactylus pentadactylus (Laurenti).
Eleutherodactylus biporcatus (Peters).
Eleutherodactylus bufoniformis (Boulenger).
Eleutherodactylus longirostris (Boulenger).
Eleutherodactylus fitzingeri (Schmidt).
Eleutherodactylus ockendeni (Boulenger).
Eleutherodactylus cruentus (Peters).
Eleutherodactylus lulosus molinoi (Barbour)
Eleutherodactylus gaigae (Dunn).
Eleutherodactylus diastema (Cope).

Brachycephalidae:

- Dendrobates minutus minutus* Shreve.
Dendrobates auratus (Girard).
Phyllobates nubicola flotator Dunn.

Hylidae:

- Hyla albomarginata* Spix.
Hyla sordida Peters.
Hyla phaeota Cope.
Hyla underwoodi Boulenger.
Hyla boulengeri (Cope).
Centrolene prosoblepon (Boettger).
Centrolene parambae (Boulenger).
Centrolene fleishmanni (Boettger).
Agalychnis spurrelli Boulenger.
Agalychnis calcarifer Boulenger.
Agalychnis callidryas (Cope).

Ranidae:

- Rana warschewitschii* (Schmidt).

MAMMALS (56)

MARSUPIALIA

- Didelphis marsupialis etensis* Allen (opossum).
Marmosa rufatanica isthmica Goldman (Isthmian marmosa).
Philander opossum fuscogriseus Allen (Allen's opossum).
Metachirus nudicaudatus dentaneus Goldman (brown opossum).
Caluromys derbianus derbianus Waterhouse (woolly opossum).

EDENTATA

- Bradypus griseus griseus* (Gray) (3-toed sloth).
Choloepus hoffmanni Peters (2-toed sloth).
Cyclopes didactylus dorsalis (Gray) (2-toed anteater).
Tamandua tetradactyla chiriquensis Allen (3-toed anteater).
Dasybus novemcinctus fenestratus Peters (9-banded armadillo).

ARTIODACTYLA

- Mazama satorii reperticia* Goldman (brocket deer).
Odocoileus virginianus chiriquensis Allen (white-tailed deer).
Tayassu tajacu bangsi Goldman (collared peccary).
Tayassu pecari spiradens Goldman (white-lipped peccary).

PERISSODACTYLA

- Tapirella bairdii* (Gill) (Baird's tapir).

RODENTIA

- Coendou rothschildi* Thomas (porcupine).
Cuniculus paca virgatus (Bangs) (conejo pintado, paca).
Dasyprocta punctata isthmica Alston (agouti, ñequi).
Heteromys desmarestianus zonalis Goldman (Canal Zone spiny pocket mouse).
Oecomys endersi Goldman (Ender's rat).
Oryzomys caliginosus chrysomelas Allen (dusky rice rat).
Oryzomys fulvescens costaricensis Allen (pigmy rice rat).
Oryzomys talamancæ talamancæ Allen (Talamanca rice rat).
Oryzomys tectus frontalis Goldman (Corozal rice rat).
Rattus rattus rattus Linnaeus (black rat).
Sigmodon hispidus chiriquensis Allen (Boqueron cotton rat).

Zygodontomys cherriei ventriosus Goldman (Canal Zone cane rat).
Proechimys semispinosus panamensis Thomas (spiny rat).
Microsciurus alfari venustulus Goldman (Canal Zone pygmy squirrel).
Sciurus granatensis morulus Bangs (Canal Zone squirrel).

LAGOMORPHA

Sylvilagus brasiliensis gabbi (Allen) (forest rabbit).

CARNIVORA

Jentinkia sumichrasti notinus Thomas (bassariscus).
Nasua narica panamensis Allen (coati-mundi, gato solo).
Potos flavus isthmicus Goldman (kinkajou).
Procyon cancrivorus panamensis (Goldman) (crab-eating raccoon).
Eira barbara biologiae (Thomas) (tayra, black cat).
Lutra repanda Goldman (otter, nutria).
Felis concolor costaricensis Merriam (puma, leon).
Felis onca centralis Mearns (jaguar, tiger).
Felis pardalis mearnsi Allen (ocelot, tigrillo).
Felis yagouaroundi panamensis (Allen) (yagouaroundi).

CHIROPTERA

Artibeus jamaicensis palmarum (Allen) (Trinidad fruit bat).
Artibeus cinereus watsoni Thomas (Watson's bat).
Carollia perspicillata azteca Saussure (short-tailed bat).
Micronycteris megalotis microtis Miller (Nicaraguan small-eared bat).
Molossus coibensis Allen (Coiba Island mastiff bat).
Myotis nigricans nigricans (Schinz) (little black bat).
Noctilio leporinus leporinus (Linnaeus) (fish-eating bat).
Phyllostomus discolor discolor (Wagner).
Rhynchiscus naso priscus G. M. Allen (Mexican long-nosed bat).
Saccopteryx bilineata (Temminck) (greater white-lined bat).
Thyroptera albiventer (Tomes) (disc bat).

PRIMATES

Alouatta palliata aequatorialis Festa (howling monkey, mono negro).
Aotus zonalis Goldman (night monkey).
Cebus capucinus imitator Thomas (white-faced monkey, cari-blanco).
Marikina goeffroyi (Pucheran) (marmoset, mono titi).

RAINFALL

In 1949, during the dry season, rains of 0.01 inch or more fell on 27 days (50 hours), and during the wet season, on 214 days (949 hours); a total during the year of 241 days (999 hours). Rainfall was above the 25-year station average. November was the rainiest month (30 days, 211 hours). The dry season was the driest on record throughout the Isthmus. It began on December 19, 1948, and continued until nearly the end of April. The rainy season continued till the

early part of December. The first 4 months of 1949 had a deficiency of 5.22 inches. The rainy season showed an excess of 13.32 inches, giving an excess of 8.10 inches for the year.

TABLE 1.—*Annual rainfall, Barro Colorado Island, C. Z.*

<i>Year</i>	<i>Total inches</i>	<i>Station average</i>
1925.....	104. 37	-----
1926.....	118. 22	113. 56
1927.....	116. 36	114. 68
1928.....	101. 52	111. 35
1929.....	87. 84	106. 56
1930.....	76. 57	101. 51
1931.....	123. 30	104. 69
1932.....	113. 52	105. 76
1933.....	101. 73	105. 32
1934.....	122. 42	107. 04
1935.....	143. 42	110. 35
1936.....	93. 88	108. 98
1937.....	124. 13	110. 12
1938.....	117. 09	110. 62
1939.....	115. 47	110. 94
1940.....	86. 51	109. 43
1941.....	91. 82	108. 41
1942.....	111. 10	108. 55
1943.....	120. 29	109. 20
1944.....	111. 96	109. 30
1945.....	120. 42	109. 84
1946.....	87. 38	108. 81
1947.....	77. 92	107. 49
1948.....	83. 16	106. 43
1949.....	114. 86	106. 76

TABLE 2.—*Comparison of 1947 and 1948 rainfall, Barro Colorado Island, C. Z.*
(inches)

Month	Total		Station average	Years of record	Excess or deficiency	Accumulated excess or deficiency
	1948	1949				
January.....	1.84	0.70	1.79	24	-1.09	-1.09
February.....	.19	.07	1.17	24	-1.10	-2.19
March.....	.17	.11	1.31	24	-1.20	-3.39
April.....	2.92	.90	2.73	25	-1.83	-5.22
May.....	10.80	11.97	10.90	25	+1.07	-4.15
June.....	6.32	15.57	11.28	25	+4.29	+.14
July.....	11.45	13.38	11.68	25	+1.70	+1.84
August.....	10.46	9.99	12.34	25	-2.35	-.51
September.....	6.72	7.11	10.15	25	-3.04	-3.55
October.....	10.74	14.45	13.12	25	+1.33	-2.22
November.....	20.33	32.76	19.40	25	+13.36	+11.14
December.....	1.22	7.85	10.89	25	-3.04	+8.10
Year.....	83.16	114.86	106.76	-----	-----	+8.10
Dry season.....	5.12	1.78	7.00	-----	-----	-5.22
Wet season.....	78.04	113.08	99.76	-----	-----	+13.32

FISCAL REPORT

During the fiscal year 1950, \$10,609.04 in trust funds was available. Of this amount \$10,502.83 was spent, leaving a balance of \$106.21. In addition to this, \$1,184.88 is still on deposit, representing local collections.

The following items are paid out of trust funds: Food, ice, fuel, salaries and wages, office expenses, telephone, laboratory supplies, freight and express, laundry, and new parts, repairs to floating equipment and to generators, general upkeep, and repairs.

During the year only \$742 was collected as fees from scientists. This decline is largely due to the high cost of transportation to the Isthmus, which keeps many from coming. Despite the higher costs of food, wages, and other items, the laboratory has not increased its per diem charge to scientists, and continues to give a 25-percent discount to those who come from institutions that sustain table subscriptions.

The following institutions continued their support to the laboratory through the payment of table subscriptions:

Eastman Kodak Co.....	\$1,000
University of Chicago.....	300
New York Zoological Society.....	300
American Museum of Natural History.....	300
Smithsonian Institution.....	300

It is again most gratifying to record donations from Dr. Eugene Eisenmann.

The Smithsonian Institution contributed \$4,500 from its private funds, in addition to its table fees. This is included in the \$10,609.04 in trust funds.

The sum of \$5,000 was made available by the Smithsonian Institution from appropriated funds, and of the amount \$4,988.97 was used for permanent improvements.

Respectfully submitted.

JAMES ZETEK, *Resident Manager.*

Dr. ALEXANDER WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 11

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the Smithsonian Library for the fiscal year ended June 30, 1950:

The primary obligation of the library in "the increase and diffusion of knowledge" is to make constantly available to the scientific and curatorial staff of the Smithsonian Institution the published records of work done or in progress throughout the world in the subject fields of the Institution's special activities and responsibilities. All the detailed procedures necessary to meeting this obligation are directed toward this end. None of them are ends in themselves, and records of them are at best only quantitative indications of growth and accomplishment. Mere numbers of publications acquired and handled mean little unless those publications have been selected with discrimination and, in terms of contemporary library parlance, "processed" for effective use, with the special requirements of the Smithsonian Institution always in mind. The final test of the quality of the library's work is the thoroughness with which an investigator has been able to canvass all the literature necessary to the successful completion or continuation of work on his particular piece of scientific research or curatorial assignment. No new scientific project, however unique, can be launched without dependence upon scientific literature.

The daily record of publications delivered to the library shows a total of 53,035 for the year, 5,102 of which were shipped from abroad through the International Exchange Service. As usual, these books, pamphlets, and serial publications came from all over the world and were written in many different languages. They covered all the subjects with which the work of the Institution is directly concerned, and many related ones as well.

The outstanding gift of the year was the fine library of some 4,000 books and pamphlets on Foraminifera collected by the late Dr. Joseph A. Cushman, which, with its own catalog, accompanied and is to be kept with the Cushman foraminiferal collection bequeathed by Dr. Cushman to the Smithsonian Institution. This library is probably unexcelled for current completeness, and additions are to be made to it in future.

Neil M. Judd's gift of his personal collection of some 500 books and papers on archeological subjects made it possible for the division of archeology to continue to have the use of this literature after Mr. Judd's retirement.

Acknowledgments for 7,392 gifts received were sent to many different donors to whom the library owes a lasting debt of gratitude for their generous contributions.

The first published appearance of information about new discoveries, inventions, and the progress of science, technology, and the arts in general is usually to be found in serial publications, which consequently are of the utmost importance in a scientific library. A great many of those the Institution regularly receives are sent by organizations and institutions with which it is in continuing exchange. Except for the issues represented by 287 paid subscriptions, most of the 16,961 parts of periodicals currently entered were exchange publications. In the course of the year 344 new exchanges were arranged, and 7,016 volumes and parts needed to complete sets, or for other purposes, were obtained in response to 604 special requests.

A good catalog is the key to the contents of the library, and good cataloging is a basic requirement of efficient library service. Upon its quality and completeness depends the ease or difficulty with which the resources of the library can be discovered. The classification and subject analysis of complex scientific publications, many of them written in foreign languages, is scholarly work. The cards filed in catalogs and shelflists are the clerical records of that work. During the past year 6,822 publications were fully cataloged, and 30,006 catalog and shelflist cards were filed. The work of correlating the central periodical records with those of the central catalog was continued, and 1,000 entries were checked and accurately unified. Neither the central catalog nor the individual catalogs of the different bureau libraries can be the fully effective instruments that they ought to be until the very large number of unclassified and incompletely cataloged publications throughout the Institution can be properly cataloged. This is so large an undertaking that a special corps of catalogers would be needed to complete it within a predictable period of time.

In all, 18,719 publications were sent to the Library of Congress. Of this number 6,053 volumes and parts were marked and recorded as permanent additions to the Smithsonian Deposit. Other publications included 1,303 doctoral dissertations, received chiefly from continental European universities. The remainder were foreign and domestic documents and miscellaneous books, pamphlets, and periodicals on subjects not of immediate interest to the Institution.

A considerable number of publications on special subjects were sent to other scientific libraries of the Government. Included among them were 776 medical dissertations and 2,058 other publications on medical subjects sent to the Army Medical Library, and 416 agricultural publications sent to the Department of Agriculture.

Records of binding show that funds were sufficient to permit 1,511 volumes, chiefly periodicals, to be sent to the Government Printing Office. Repairs to 1,023 volumes were made in the Museum library. The deterioration of completed volumes of periodicals that must wait for sufficient funds before they can be bound is one of the serious problems of the library, as is the care and repair of the many old books, some of them irreplaceable, that the Institution is so fortunate as to own. The library is in no sense a museum of fine books. It is an active working collection, but the very character of the Institution's responsibilities, especially in connection with the work of the National Museum, makes it inevitable that many old as well as new books should be in constant use as tools. That some of them happen to be also collectors' items is incidental but makes their care and protection doubly important.

It was not possible to undertake further work on the organization of the large collection of duplicates and unstudied material housed in the west stacks, but more than 36,000 pieces, mostly parts of periodicals previously checked and arranged, were sent to the United States Book Exchange to be used as opportunity offers in exchange for material drawn from the stockpile of that center.

No reliable figure showing over-all use of the library can be given. The large decentralization of its collections, especially in the Museum, where 30 of its sectional libraries are in the custodial charge of the curators, makes it impractical to attempt to keep statistical records of the intramural use of books and periodicals. Loan-desk records show that 12,522 publications were borrowed for use outside the library, 2,181 of which were interlibrary loans made to 104 different Government, university, and other institutional libraries throughout the country.

Loans are not made to individuals other than staff members and affiliates of the Institution, but the resources of the library are open to any individual who wishes to make reference use of them, either by coming in person or by telephoning or writing to the library. The library receives hundreds of requests for information in the course of the year, and whether the inquirer is a scholarly research worker or a casual sightseer, a foreign correspondent or a rural schoolboy, the staff makes every effort to see that his question is answered, either by finding and giving him the requested information or by referring him

to an appropriate authority elsewhere. This is by no means an unimportant part of the "diffusion of knowledge," and especially in terms of good will, is a richly rewarding one.

It is regrettable that no relief for the overcrowding of the library can be reported.

SUMMARIZED STATISTICS

Accessions

	Volumes	Total recorded volumes June 30, 1950
Astrophysical Observatory (including Radiation and Organisms).....	500	13,573
Bureau of American Ethnology.....	119	34,838
National Air Museum.....	86	126
National Collection of Fine Arts.....	384	12,175
National Museum.....	2,735	246,401
National Zoological Park.....	3	4,196
Smithsonian Deposit at the Library of Congress.....	1,629	582,280
Smithsonian Office.....	375	33,448
Total.....	5,831	927,037

Neither incomplete volumes of periodicals nor separates and reprints from periodicals are included in these figures.

Exchanges

New exchanges arranged.....	344
107 of these were assigned to the Smithsonian Deposit in the Library of Congress.	
Specially requested publications received.....	7,016
1,026 of these were obtained to fill gaps in the Smithsonian Deposit sets.	

Cataloging

Volumes and pamphlets cataloged.....	6,822
Cards added to catalogs and shelflists.....	30,006

Periodicals

Periodical parts entered.....	16,961
-------------------------------	--------

Circulation

Loans of books and periodicals.....	12,522
This figure does not include the intramural circulation of books and periodicals filed in the sectional libraries of the Museum.	

Binding

Volumes sent to the bindery.....	1,511
Volumes repaired in the Museum.....	1,023

Respectfully submitted.

LEILA F. CLARK, *Librarian.*

Dr. A. WETMORE,
Secretary, Smithsonian Institution.

APPENDIX 12

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches for the year ended June 30, 1950:

The Institution published during the year 12 papers in the Smithsonian Miscellaneous Collections, 1 Annual Report of the Board of Regents and pamphlet copies of 22 articles in the report appendix, 1 Annual Report of the Secretary, and a reprint of 1 special publication.

The United States National Museum issued 1 Annual Report, 22 Proceedings papers, 2 Bulletins, and 4 Contributions from the United States National Herbarium.

The Bureau of American Ethnology issued 1 Annual Report, 1 Bulletin, and 1 Publication of the Institute of Social Anthropology.

The National Collection of Fine Arts issued 1 catalog.

The Freer Gallery of Art issued 1 paper in its Oriental Studies series and 1 in its Occasional Papers series.

Of the publications there were distributed 150,612 copies, which included 26 volumes and separates of Smithsonian Contributions to Knowledge, 26,489 volumes and separates of Smithsonian Miscellaneous Collections, 28,248 volumes and separates of Smithsonian Annual Reports, 3,619 War Background Studies, 5,918 Smithsonian special publications, 40 reports and 211 sets of pictures of the Harriman Alaska Expedition, 57,938 volumes and separates of National Museum publications, 14,877 publications of the Bureau of American Ethnology, 4,239 publications of the Institute of Social Anthropology, 38 catalogs of the National Collection of Fine Arts, 1,178 volumes and pamphlets of the Freer Gallery of Art, 10 Annals of the Astrophysical Observatory, 1,318 reports of the American Historical Association, and 6,463 miscellaneous publications not printed by the Smithsonian Institution (mostly Survival Manuals).

In addition, 11,523 picture pamphlets, 80,751 guide books, 30,230 natural history and art post cards, 135 sets of North American Wild Flowers, and 5 volumes of Pitcher Plants were distributed.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

In this series there were issued 10 papers in volume 111, whole volume 112, and whole volume 113, as follows:

VOLUME 111

No. 8. Some stages in the evolution of the nervous system and the fore-gut of the polychaet, by Frank Raw. 35 pp., 5 figs. (Publ. 3983.) Aug. 4, 1949.

No. 9. A new heron and a new owl from Venezuela, by Herbert Friedmann. 3 pp. (Publ. 3985.) July 21, 1949.

No. 10. A collection of fishes from Talara, Perú, by Samuel F. Hildebrand. 36 pp., 9 figs. (Publ. 3986.) Aug. 18, 1949.

No. 11. Larvae of the elaterid beetles of the tribe Lepturoidini (Coleoptera: Elateridae), by Robert Glen. 246 pp., 40 figs. (Publ. 3987.) Apr. 19, 1950.

No. 12. Note on Fowle's spectroscopic method for the determination of aqueous vapor in the atmosphere, by L. B. Aldrich. 6 pp., 1 pl., 2 figs. (Publ. 3989.) Sept. 20, 1949.

No. 13. Short periodic solar variations and the temperatures of Washington and New York, by C. G. Abbot. 8 pp., 2 figs. (Publ. 3990.) Oct. 4, 1949.

No. 14. The Abbot silver-disk pyrheliometer, by L. B. Aldrich. 11 pp., 1 pl., 1 fig. (Publ. 3991.) Dec. 8, 1949.

No. 15. The roll call of the Iroquois chiefs. A study of a mnemonic cane from the Six Nations Reserve, by William N. Fenton. 73 pp., 12 pls., 3 figs. (Publ. 3995.) Feb. 16, 1950.

No. 16. The forms of the black hawk-eagle, by Herbert Friedmann. 4 pp., 1 pl. (Publ. 4013.) Feb. 28, 1950.

No. 17. Periodic influences on Washington and New York weather of 1949 and 1950, by C. G. Abbot. 8 pp., 3 figs. (Publ. 4015.) Mar. 22, 1950.

VOLUME 112 (WHOLE VOLUME)

Catalog of the termites (Isoptera) of the world, by Thomas E. Snyder. 490 pp. (Publ. 3953.) Nov. 1, 1949.

VOLUME 113 (WHOLE VOLUME)

Archeology of the Florida Gulf coast, by Gordon R. Willey. 599 pp., 60 pls., 76 figs., 20 maps. (Publ. 3988.) Dec. 29, 1949.

SMITHSONIAN ANNUAL REPORT

Report for 1948.—The complete volume of the Annual Report of the Board of Regents for 1948 was received from the Public Printer December 28, 1949:

Annual Report of the Board of Regents of the Smithsonian Institution showing the operations, expenditures, and condition of the Institution for the year ended June 30, 1948. ix+466 pp., 100 pls., 52 figs., 1 chart. (Publ. 3954.)

The general appendix contained the following papers (Publs. 3955–3976):

The Astrophysical Observatory of the Smithsonian Institution, by C. G. Abbot.
Atomic energy in industry, by H. A. Winne.

High-altitude research with V-2 rockets, by Ernest H. Krause.
 Roentgen rays against cancer, by John G. Trump.
 The optical glass industry, past and present, by Francis W. Glaze.
 The age of the earth, by Arthur Holmes.
 Petroleum resources of North America, by A. I. Levorsen.
 American meteorites and the National collection, by E. P. Henderson.
 Glacial varved clay concretions of New England, by Ray S. Bassler.
 Algal pillars miscalled geyser cones, by Roland W. Brown.
 Concepts in conservation of land, water, and wildlife, by Ira N. Gabrielson.
 The evolution and function of genes, by A. H. Sturtevant.
 The sense organs of birds, by R. J. Pumphrey.
 Insect control investigations of the Orlando, Fla., laboratory during World War II, by E. F. Knipling.
 The golden nematode invades New York, by W. L. Popham.
 The cork oak in the United States, by Victor A. Ryan and Giles B. Cooke.
 Remember the chestnut! by Amanda Ulm.
 The numbers and distribution of mankind, by C. B. Fawcett.
 Mexican calendars and the solar year, by Herbert J. Spinden.
 Surviving Indian groups of the eastern United States, by William Harlen Gilbert, Jr.
 Recently published Greek papyri of the New Testament, by Bruce M. Metzger.
 Japanese art—a reappraisal, by Robert T. Paine, Jr.

Report for 1949.—The Report of the Secretary, which included the financial report of the executive committee of the Board of Regents, and which will form part of the Annual Report of the Board of Regents to Congress, was issued December 29, 1949:

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ended June 30, 1949. ix+149 pp. (Publ. 3992.)

SPECIAL PUBLICATIONS

Smithsonian Mathematical Tables. Hyperbolic functions. Sixth reprint. Prepared by George F. Becker and C. E. Van Orstrand. lii+321 pp. (Publ. 1871.) 1949.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 Annual Report, 22 Proceedings papers, 2 Bulletins, and 4 separate papers in the Contributions from the United States National Herbarium, as follows:

REPORT

Report on the progress and condition of the United States National Museum for the year ended June 30, 1949. iii+123 pp. Jan. 13, 1950.

PROCEEDINGS: VOLUME 97

Title page, table of contents, list of illustrations, and index. Pp. i-vii, 571-601 Jan. 26, 1950.

VOLUME 99

No. 3248. Additions to the echiuroid fauna of the North Pacific Ocean, by Walter Kenrick Fisher. Pp. 479-497, pls. 28-34. Aug. 10, 1949.

No. 3249. A remarkable new species of trypetid fly of the genus *Ceratitis* (sensu stricto) from East Africa in the collection of the United States National Museum, by H. K. Munro. Pp. 499-501, fig. 39. July 5, 1949.

No. 3250. A new marine annelid from Florida, by Olga Hartman. Pp. 503-508, fig. 40. Aug. 4, 1949.

No. 3251. A new species of apseudid crustacean of the genus *Synapseudes* from northern California (Tanaidacea), by Robert J. Menzies. Pp. 509-515, figs. 41-42. Aug. 4, 1949.

No. 3252. Redescription of the shrimp *Bathypalaemonella pandaloides* (Rathbun), with remarks on the family Campylonotidae, by L. B. Holthuis. Pp. 517-523, fig. 43. Aug. 25, 1949.

No. 3253. The Nearctic species of Evaniidae (Hymenoptera), by Henry Townes. Pp. 525-539, fig. 44. Sept. 1, 1949.

VOLUME 100

No. 3254. On a collection of Mallophaga from Guam, Marianas Islands, by M. A. Carriker, Jr. Pp. 1-24, figs. 1-5. Nov. 29, 1949.

No. 3255. Observations on flatworms and nemerteans collected at Beaufort, N. C., by A. S. Pearse. Pp. 25-38, figs. 6-9. Oct. 14, 1949.

No. 3256. Some Alaskan syrphid flies, with descriptions of new species, by C. L. Fluke. Pp. 39-54, figs. 10-11. Oct. 11, 1949.

No. 3257. Two new gynandromorphs, with a list of previously recorded sexual aberrations in the scolioid wasps, by Karl V. Krombein. Pp. 55-59, pls. 1-2. Nov. 16, 1949.

No. 3258. Fresh-water Ostracoda from Brazil, by Willis L. Tressler. Pp. 61-83, figs. 12-14. Jan. 8, 1950.

No. 3259. The Nearctic species of Gasteruptiidae (Hymenoptera), by Henry Townes. Pp. 85-145, figs. 15-16. Apr. 18, 1950.

No. 3260. Pycnogonida of the United States Navy Antarctic Expedition, 1947-48, by Joel W. Hedgpeth. Pp. 147-160, figs. 17-19. Jan. 23, 1950.

No. 3261. Copepods from Lake Erh Hai, China, by Sidney C. Hsiao. Pp. 161-200, figs. 20-30. Apr. 26, 1950.

No. 3262. Mosquitoes of the genus *Tripteroides* in the Solomon Islands, by John N. Belkin. Pp. 201-274, figs. 31-37. Mar. 30, 1950.

No. 3263. A revision of the American clupeid fishes of the genus *Harengula*, with descriptions of four new subspecies, by Luis René Rivas. Pp. 275-309, pls. 3-5, figs. 38-41. Mar. 28, 1950.

No. 3264. Moths of the genus *Cincia* and three new and closely related genera, by William D. Field. Pp. 311-326, pls. 6-9. Mar. 10, 1950.

No. 3265. Mammals of northern Colombia. Preliminary report No. 6: Rabbits (Leporidae), with notes on the classification and distribution of the South American forms, by Philip Hershkovitz. Pp. 327-375, figs. 42-43. May 26, 1950.

No. 3266. Some bird lice of the genera *Acidoproctus* and *Quadriceps* (Neotropical Mallophaga Miscellany No. 3), by M. A. Carriker, Jr. Pp. 377-386, figs. 44-45. Jan. 26, 1950.

No. 3267. A review of the American clupeid fishes of the genus *Dorosoma*, by Robert Rush Miller. Pp. 387-410. Mar. 7, 1950.

No. 3268. A contribution to the ornithology of northeastern Venezuela, by Herbert Friedmann and Foster D. Smith, Jr. Pp. 411-538, pls. 10-12, figs. 46-50. Mar. 10, 1950.

BULLETINS

197. Life histories of North American wagtails, shrikes, vireos, and their allies. Order Passeriformes, by Arthur Cleveland Bent. Pp. i-vii, 1-411, 48 pls. June 21, 1950.

198. Catalog of the automobile and motorcycle collection of the Division of Engineering, United States National Museum, by Smith Hempstone Oliver. Pp. i-iv, 1-62, 18 pls. May 9, 1950.

CONTRIBUTIONS FROM THE UNITED STATES NATIONAL HERBARIUM

VOLUME 29

Part 7. Studies in the Bromeliaceae, XV, by Lyman B. Smith. Pp. i-vii, 277-316, figs. 2-36. Dec. 28, 1949.

Part 8. Studies of South American plants, XII, by A. C. Smith. Pp. i-viii, 317-393. Jan. 23, 1950.

Part 9. New grasses from Mexico, Central America, and Surinam, by Jason R. Swallen. Pp. i-v, 395-428. Mar. 7, 1950.

VOLUME 30

Part 3. Additional phanerogams in the flora of Guam, with notes on unverified records, by Egbert H. Walker and Robert Rodin. Pp. i-vi, 449-468, pls. 8-9. Aug. 25, 1949.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the Bureau continued under the immediate direction of the editor, M. Helen Palmer. During the year there were issued 1 Annual Report, 1 Bulletin, and 1 Publication of the Institute of Social Anthropology, as follows:

REPORT

Sixty-sixth Annual Report of the Bureau of American Ethnology, 1948-1949. 34 pp.

BULLETIN

143. Handbook of South American Indians. Julian H. Steward, editor. Volume 5, The comparative ethnology of South American Indians. xxvi+818 pp., 56 pls., 190 figs., 22 maps. 1949.

PUBLICATIONS OF THE INSTITUTE OF SOCIAL ANTHROPOLOGY

No. 10. Nomads of the Long Bow: The Siriono of eastern Bolivia, by Allan R. Holmberg. 104 pp., 7 pls., 4 charts, 1 map. 1950.

PUBLICATIONS OF THE NATIONAL COLLECTION OF FINE ARTS

Centennial exhibition of paintings by Abbott Handerson Thayer, N. A. (1849-1921), August 12 through December 1949. 4 pp. 1949.

PUBLICATIONS OF THE FREER GALLERY OF ART

ORIENTAL STUDIES

No. 4. Shiraz painting in the sixteenth century, by Grace Dunham Guest. 70 pp., 50 pls., 15 figs. (Publ. 3978.) 1949.

OCCASIONAL PAPERS: VOLUME 1

No. 4. James McNeill Whistler: A biographical outline, illustrated from the collections of the Freer Gallery of Art, by Burns A. Stubbs. 29 pp., 28 pls. (Publ. 3994.) 1950.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the Association to the Secretary of the Smithsonian Institution and are by him communicated to Congress, as provided by the act of incorporation of the Association. The following report volume was issued this year:

Annual Report of the American Historical Association, 1948. Vol. 1. Proceedings.

The following was in press at the close of the fiscal year:

Annual Report of the American Historical Association for 1949. Vol. 1. Proceedings.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Fifty-second Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, December 13, 1949.

APPROPRIATION FOR PRINTING AND BINDING

The congressional appropriation for printing and binding for the past year was entirely obligated at the close of the year. The appropriation for the coming fiscal year ending June 30, 1951, totals \$103,000, allotted as follows:

General administration (Annual Report of the Board of Regents; Annual Report of the Secretary).....		\$18, 500
National Museum.....		36, 200
Bureau of American Ethnology.....		21, 500
National Air Museum.....		500
Service divisions (Annual Report of the American Historical Association; blank forms; binding; Museum print shop).....		26, 300
		<hr/> 103, 000

Webster P. True, who had been associated with the Institution as editor for nearly 36 years—19 years in charge of the consolidated editorial offices and since 1940 as Chief of the Editorial Division—retired on May 31, 1950.

Respectfully submitted.

PAUL H. OEHSER, *Chief, Editorial Division.*

Dr. A. WETMORE,

Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1950

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8s. 6d.—\$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, and other incidental expenses, together with payment into the fund of the sum, £5,015, which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of \$550,000.

Since the original bequest, the Institution has received gifts from various sources, the income from which may be used for the general work of the Institution. These, including the original bequest, plus savings, are listed below, together with the income for the present year.

ENDOWMENT FUNDS

(Income for unrestricted use of the Institution)

Partly deposited in United States Treasury at 6 percent and partly invested in stocks, bonds, and other holdings.

Fund	Investment	Income present year
Parent fund (original Smithson bequest, plus accumulated savings).....	\$728,891.33	\$43,712.50
Subsequent bequests, gifts, and other funds, partly deposited in the U. S. Treasury and partly invested in the consolidated fund:		
Avery, Robert S., and Lydia, bequest fund.....	54,487.74	2,591.14
Endowment fund.....	346,910.62	14,753.47
Habel, Dr. S., bequest fund.....	500.00	30.00
Hachenberg, George P. and Caroline, bequest fund.....	4,122.41	178.29
Hamilton, James, bequest fund.....	2,913.78	167.87
Henry, Caroline, bequest fund.....	1,239.68	53.58
Hodgkins, Thomas G. (general gift).....	146,733.43	8,289.26
Porter, Henry Kirke, memorial fund.....	293,560.53	12,696.91
Rhees, William Jones, bequest fund.....	1,074.91	56.34
Sanford, George H., memorial fund.....	2,012.48	105.46
Witherspoon, Thomas A., memorial fund.....	132,279.68	5,721.29
Special fund, stock in reorganized closed banks.....	2,280.00	160.00
Total.....	988,115.26	44,803.61
Grand total.....	1,717,006.59	88,516.11

The Institution holds also a number of endowment gifts, the income of each being restricted to specific use. These, plus accretions to date, are listed below, together with income for the present year.

Fund	Investment	Income present year
Abbott, William L., fund, for investigations in biology	\$103,134.07	\$4,468.79
Arthur, James, fund, for investigations and study of the sun and lecture on same	40,994.19	1,773.04
Bacon, Virginia Purdy, fund, for traveling scholarship to investigate fauna of countries other than the United States	51,354.63	2,221.13
Baird, Lucy H., fund, for creating a memorial to Secretary Baird	24,679.35	1,067.41
Barstow, Frederick D., fund, for purchase of animals for Zoological Park	1,024.77	44.31
Canfield collection fund, for increase and care of the Canfield collection of minerals	39,204.24	1,695.61
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera	10,401.67	406.62
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks	28,865.24	1,248.46
Eickemeyer, Florence Brevoort, fund, for preservation and exhibition of the photographic collection of Rudolph Eickemeyer, Jr.	10,996.44	230.03
Hillyer, Virgil, fund, for increase and care of Virgil Hillyer collection of lighting objects	6,736.68	291.34
Hitchcock, Dr. Albert S., library fund, for care of Hitchcock Agrostological Library	1,617.40	69.93
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air	100,000.00	6,000.00
Hrdlička, Aleš and Marie, fund, to further researches in physical anthropology and publication in connection therewith	18,851.21	815.31
Hughes, Bruce, fund, to found Hughes alcove	19,620.33	848.57
Long, Annette and Edith C., fund, for upkeep and preservation of Long collection of embroideries, laces, and textiles	556.57	24.04
Maxwell, Mary E., fund, for care and exhibition of Maxwell collection	20,105.37	437.04
Myer, Catherine Walden, fund, for purchases of first-class works of art for the use and benefit of the National Collection of Fine Arts	19,430.11	840.35
Strong, Julia D., bequest fund, for benefit of the National Collection of Fine Arts	10,248.68	443.24
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell Collection	7,597.97	328.62
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to \$250,000	126,446.10	5,573.40
Rathbun, Richard, memorial fund, for use of division of U. S. National Museum containing Crustacea	10,902.13	471.52
Reid, Addison T., fund, for founding chair in biology, in memory of Asher Tunis	30,416.71	1,530.14
Roebbling Collection fund, for care, improvement, and increase of Roebbling collection of minerals	123,708.61	5,350.58
Rollins, Miriam and William, fund, for investigations in physics and chemistry	96,247.31	4,160.11
Smithsonian employees' retirement fund	32,936.77	1,501.70
Springer, Frank, fund, for care and increase of Springer collection and library	18,381.62	795.00
Walcott, Charles D. and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof	384,948.48	13,403.72
Younger, Helen Walcott, fund, held in trust	46,610.54	1,382.45
Zerbe, Frances Brincklé, fund, for endowment of aquaria	972.27	42.03
Total	1,386,989.46	57,464.49

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other Oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally in his will, probated November 6, 1919, he provided stock and securities to the estimated value of \$1,958,591.42, as an endowment fund for the operation of the Gallery.

The above fund of Mr. Freer was almost entirely represented by 20,465 shares of stock in Parke, Davis & Co. As this stock advanced in value, much of it was sold and the proceeds reinvested so that the fund now amounts to \$6,420,811.53 in selected securities.

SUMMARY OF ENDOWMENTS

Invested endowment for general purposes.....	\$1, 717, 006. 59
Invested endowment for specific purposes other than Freer endowment.....	1, 386, 989. 46
Total invested endowment other than Freer endowment..	3, 103, 996. 05
Freer invested endowment for specific purposes.....	6, 420, 811. 53
Total invested endowment for all purposes.....	9, 524, 807. 58

CLASSIFICATION OF INVESTMENTS

Deposited in the U. S. Treasury at 6 percent per annum, as authorized in the U. S. Revised Statutes, sec. 5591.....	\$1, 000, 000. 00
Investments other than Freer endowment (cost or market value at date acquired):	
Bonds.....	\$747, 993. 56
Stocks.....	1, 251, 101. 70
Real estate and first-mortgage notes.....	59, 938. 40
Uninvested capital.....	44, 962. 39
	2, 103, 996. 05
Total investments other than Freer endowment.....	3, 103, 996. 05
Investment of Freer endowment (cost or market value at date acquired):	
Bonds.....	\$3, 539, 132. 19
Stocks.....	2, 853, 927. 77
Uninvested capital.....	27, 751. 57
	6, 420, 811. 53
Total investments.....	9, 524, 807. 58

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING FISCAL YEAR 1950¹

Cash balance on hand June 30, 1949.....	\$530, 330. 73
Receipts, other than Freer endowment:	
Income from investments.....	\$156, 125. 11
Gifts and contributions.....	77, 703. 66
Sales of publications.....	34, 488. 82
Miscellaneous.....	31, 538. 15
Proceeds from real-estate holdings.....	2, 038. 67
Total receipts other than Freer endowment.....	301, 894. 41

¹ This statement does not include Government appropriations under the administrative charge of the Institution.

Receipts from Freer endowment:

Income from investments.....	\$296, 293. 08	
Total receipts from Freer endowment.....		\$296, 293. 08
<hr/>		
Total.....		1, 128, 518. 22

Disbursements other than Freer endowment:

Administration.....	\$49, 172. 30	
Publications.....	40, 605. 33	
Library.....	4, 272. 10	
Custodian fees and similar incidentals.....	3, 372. 70	
Miscellaneous.....	442. 43	
Researches.....	182, 364. 45	
S. I. Retirement System.....	3, 728. 28	
U. S. Govt. and other contracts (net).....	9, 618. 65	
Purchase and sale securities (net).....	50, 540. 69	
Payroll withholdings and refunds of advances (net).....	3, 729. 13	

Total disbursements other than Freer endowment..... 347, 846. 06

Disbursements from Freer endowment:

Salaries.....	\$83, 214. 19	
Purchases for collections.....	155, 900. 00	
Custodian fees and similar incidentals.....	12, 578. 48	
Miscellaneous.....	43, 540. 86	
Purchase and sale of securities (net).....	5, 690. 11	

Total disbursements from Freer endowment..... 300, 923. 64

Investment of current funds in U. S. Bonds..... 100, 098. 39

Total disbursements..... 748, 868. 09

Cash balance June 30, 1950..... 379, 650. 13

Total..... 1, 128, 518. 22

ASSETS

Cash:

United States Treasury current account.....	\$266, 007. 26	
In banks and on hand.....	113, 642. 87	

379, 650. 13

Less uninvested endowment funds.. 72, 713. 96

\$306, 936. 17

Travel and other advances..... 24, 910. 28

Cash invested (U. S. Treasury Notes)..... 602, 953. 13

\$934, 799. 58

Investments—at book value:

Endowment funds:

Freer Gallery of Art:

Stocks and bonds.....\$6, 393, 059. 96

Uninvested capital... 27, 751. 57

6, 420, 811. 53

Investments—at book value—Continued

Investments at book value

other than Freer:

Stocks and bonds-----	\$1,999,095.26	
Real estate and mortgage notes-----	59,938.40	
Uninvested capital-----	44,962.39	
Special deposit in U. S. Treasury at 6% interest.	1,000,000.00	
	<u>\$3,103,996.05</u>	
		<u>\$9,524,807.58</u>
		10,459,607.16

UNEXPENDED FUNDS AND ENDOWMENTS

Unexpended funds:

Income from Freer Gallery of Art endowment-----	\$402,032.72	
Income from other endowments:		
Restricted-----	\$186,777.56	
General-----	94,331.88	
	<u>281,109.44</u>	
Gifts and grants-----	251,657.42	
		<u>934,799.58</u>

Endowment funds:

Freer Gallery of Art-----	\$6,420,811.53	
Other:		
Restricted-----	\$1,386,989.46	
General-----	1,717,006.59	
	<u>3,103,996.05</u>	
		<u>9,524,807.58</u>
		10,459,607.16

The practice of maintaining savings accounts in several of the Washington banks and trust companies has been continued during the past year, and interest on these deposits amounted to \$696.21.

In many instances, deposits are made in banks for convenience in collection of checks, and later such funds are withdrawn and deposited in the United States Treasury. Disbursement of funds is made by check signed by the Secretary of the Institution and drawn on the United States Treasury.

The foregoing report relates only to the private funds of the Institution.

The Institution gratefully acknowledges gifts from the following:

E. J. Brown, for purchase of bird specimens.

Laura Welsh Casey, addition to capital of Thomas Lincoln Casey Fund.

Florence Brevoort Eickemeyer Estate, for preservation and care of Rudolph Eickemeyer photographic collection.

E. R. Fenimore Johnson, for researches in underwater photography.

Mary E. Maxwell Estate, income for use in preservation of Maxwell Collection.

National Academy of Sciences, for services in connection with a special mission.

National Geographic Society, for balance of expenses of expedition to Arnhem Land.

Alberto A. Eno, for establishment of Southwest Archeological Fund.

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1950:

Salaries and expenses.....	\$2, 346, 000. 00
National Zoological Park.....	544, 700. 00

In addition, funds were transferred from other Departments of the Government for expenditure under direction of the Smithsonian Institution as follows:

International Information and Educational Activities (transferred to the Smithsonian Institution from the State Department)...	\$82, 510. 00
Working Fund, transferred from the National Park Service, Interior Department, for archeological and paleontological investigations in River Basins throughout the United States...	215, 886. 00

The Institution also administers a trust fund for partial support of the Canal Zone Biological Area, located on Barro Colorado Island in the Canal Zone.

The report of the audit of the Smithsonian private funds follows:

WASHINGTON, D. C., *September 18, 1950.*

TO THE BOARDS OF REGENTS,
SMITHSONIAN INSTITUTION,

Washington 25, D. C.

We have examined the accounts of the Smithsonian Institution relative to its private endowment funds and gifts (but excluding the National Gallery of Art and other departments, bureaus, or operations administered by the Institution under Federal appropriations) for the year ended June 30, 1950. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

The Institution maintains its accounts on a cash basis and does not accrue income and expenses. Land, buildings, furniture, equipment, works of art, living and other specimens and certain sundry property are not included in the accounts of the Institution.

In our opinion, the accompanying financial statements present fairly the position of the private funds and the cash and investments thereof of the Smithsonian Institution at June 30, 1950 (excluding the National Gallery of Art and other departments, bureaus, or operations administered by the Institution under Federal appropriations) and the cash receipts and disbursements for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

PEAT, MARWICK, MITCHELL & Co.

Respectfully submitted.

ROBERT V. FLEMING
VANNEVAR BUSH
CLARENCE CANNON
Executive Committee.

GENERAL APPENDIX
TO THE
SMITHSONIAN REPORT FOR 1950

ADVERTISEMENT

The object of the **GENERAL APPENDIX** to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by staff members and collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the Secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report of 1889, a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1950.

BEYOND THE MILKY WAY¹

By THORNTON PAGE
Yerkes Observatory

[With 4 plates]

Before we can appreciate this topic it is necessary to understand precisely what is meant by the term "Milky Way" and how we can know when we are "beyond" it. Initially it is simple to define the Milky Way as the faint band of light which can be seen on clear nights to extend completely around the whole sphere of the sky and which telescopes have resolved into myriads of faint stars. As we shall see, the term has come to mean more than just what we can see; to some extent it is synonymous with the term "galaxy," which describes our concept of an organized system of stars, diffuse clouds of gas, and other material, inside of which we are located, and the study of which has occupied astronomers for several decades and will probably occupy them for several decades to come.

Why should these faint stars be distributed so peculiarly, as if in a doughnutlike ring around us? A simple interpretation comes to mind if we assume, for the moment, that all stars are intrinsically of about the same brightness. Then these faint stars of the Milky Way would be farther away than the brighter stars, their apparent brightness being less the more distant they are. (The apparent brightness of a luminous source is known from other considerations to be inversely proportional to the square of the distance.) Although refinements are necessary, this simple deduction from an unproved assumption is one of the basic methods for measuring astronomical distances. We must investigate further these distances and their measurement before the term "beyond" can have any meaning.

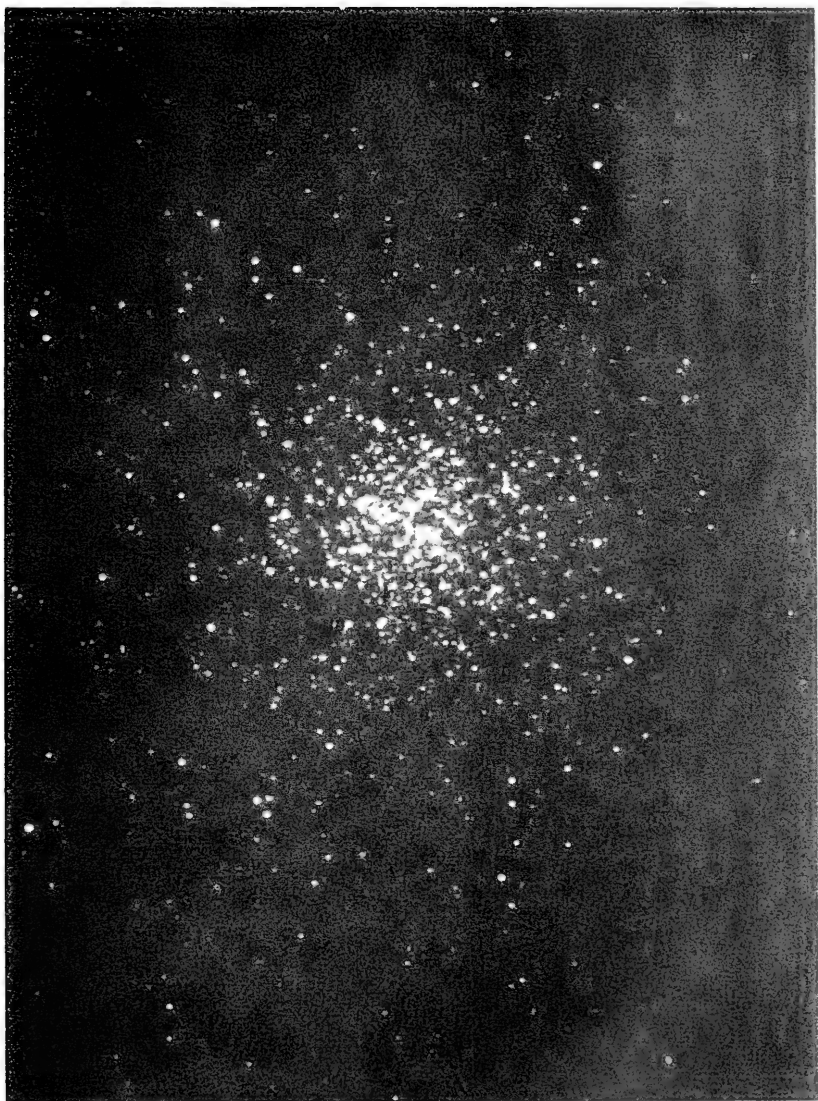
Astronomical distances are well recognized to be considerably larger than the distances we are familiar with; it is quite impossible to comprehend them in an absolute sense. But since we are concerned here only with one thing being "beyond" another, an appreciation of the *relative* sizes of various distances is sufficient. To avoid large numbers, it is convenient to use large units of distance: the "astronomical unit," which is about 100 million miles (accurately the distance to the

¹ An address given before the Cleveland Astronomical Society on November 4, 1949. Reprinted by permission from *Popular Astronomy*, vol. 57, No. 10, December 1949.

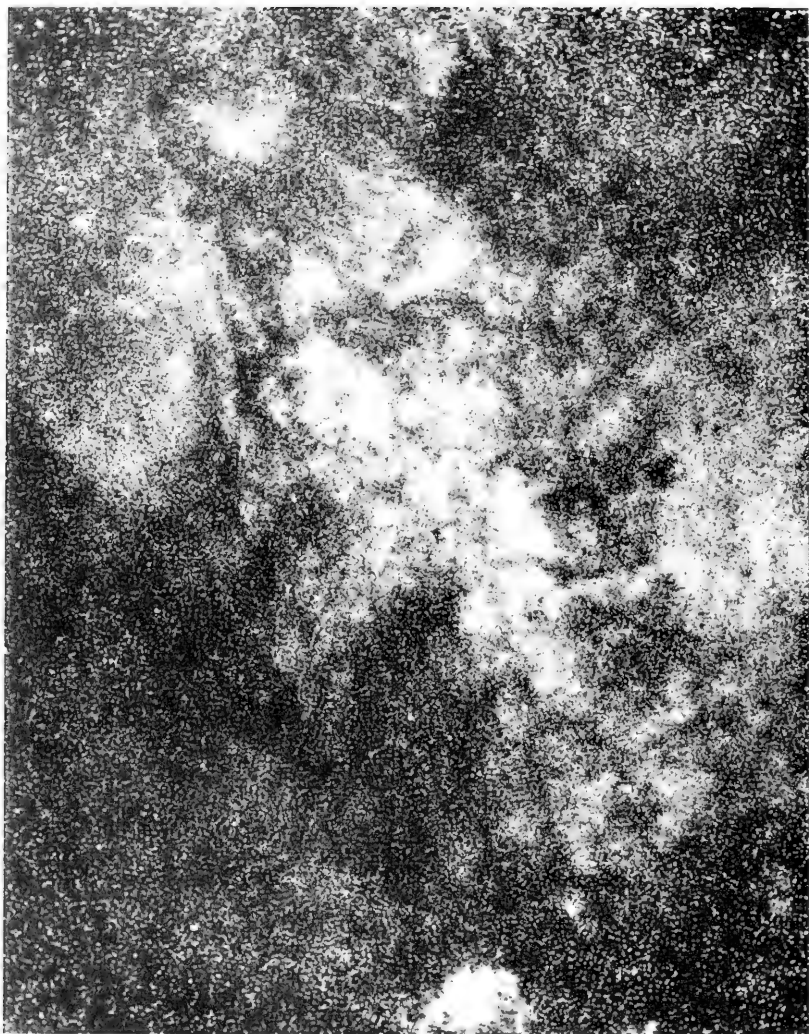
sun), and the "light-year" (some 63,000 astronomical units—or the distance light travels in 1 year).

The most basic method of measuring distances between astronomical bodies (where it is impossible to pace out, or scale off, a distance, as we can do on the earth) is triangulation, a method used by surveyors, and familiar to most of you. It depends only on the validity of the axioms of Euclidean geometry, from which the lengths of the sides of a triangle can be deduced if one side and two angles are given (or measured), and the applicability of those axioms to rays of light. Observations from the two ends of a "base line" on the earth itself can thus be used to measure the distances to the nearby members of the solar system—to the moon, sun, planets, and comets—to anything, in fact, within about 50 astronomical units, beyond which the angles involved are too small to measure. Now since the earth goes around the sun in an orbit of known dimensions, this "parallax method" can be vastly extended, by using the diameter of the earth's orbit as base line, to determine distances to stars as far as 500 light-years away. Still, the parallax method is too limited; almost all the faint stars of the Milky Way seem to be considerably farther away than 500 light-years.

Returning to the "brightness method" of measuring distance, we are disappointed to discover (after a few hundred star distances are measured by the parallax method) that our assumption of the stars being all of the same intrinsic luminosity was a poor one; some stars are only one ten-thousandth the candlepower of the sun, others 10,000 times as bright, when the effect of distance is taken into account. However, we might expect to find some subclasses of stars whose members are all of about the same brightness; in other words, we might hope to discover some earmark by which we can recognize the stars of very large candlepower—a thousand times that of the sun, say—and, after checking such a "luminosity criterion" among the closer stars whose distances are measured by the parallax method, use it to determine the distances of other stars much farther away by the brightness method. This is precisely the nature of one of the important research projects being undertaken at the Warner and Swasey Observatory by Dr. Nassau, the director, and Dr. Morgan of the Yerkes Observatory. They are using the B stars—stars of bluish hue that can also be recognized from their spectra—to determine distances to the far reaches of the Milky Way system. Previously, much the same method was applied by Dr. Shapley, first at Mount Wilson, then at the Harvard Observatory, to the now famous "Cepheid variables" whose period of fluctuation was found to be the earmark of their intrinsic luminosity. Shapley also found that certain types of clusters of stars have a total combined candlepower in each case some 30,000 times that of the sun. These "globular clusters," easily recognized by their form,



Messier 13 in the constellation Hercules, a nearby example of the class of globular clusters, each of which has a total candlepower some 30,000 times that of the sun. A more distant globular cluster appears fainter, and from this change in apparent brightness with distance, the distances of the globular clusters can be determined. (Photograph Yerkes Observatory.)



A photograph of part of the Milky Way, showing that it is formed of myriads of faint stars. (Photograph Yerkes Observatory.)



Messier 31 in the constellation Andromeda, an extragalactic nebula far beyond the confines of the Milky Way system. Because other similar nebulae are seen at all angles of tilt (from circular form, as on plate 4, to lenticular forms seen edge-on), Messier 31 is interpreted as a circular disk, tilted with one edge toward us. The two smaller bright fuzzy patches are other extragalactic nebulae (of elliptical type) at about the same distance as Messier 31. (Photograph Yerkes Observatory.)



Messier 51 in the constellation Canes Venatici, an extragalactic nebula of spiral form seen square-on.



NGC 1300, a barred spiral.

are so powerful that they can be used to measure distances up to a million light-years. Using the distances and directions of the globular clusters, Shapley plotted the positions of about 100 of them and found that they are distributed in a large spherical volume of space, the center of this array being at a point in the brightest part of the Milky Way, in the direction of the constellation Sagittarius. It was reasonable to assume, as Shapley did, that this point is the center of the Milky Way system.

At this juncture it is necessary to examine one of those refinements of method with which astronomers continually busy themselves. In using the brightness method of measuring distance, Shapley assumed that interstellar space is transparent; that the only reason one globular cluster appears fainter than another is because of its greater distance. For reasons too lengthy to indicate here, astronomers now know that dust and gas between the stars also dim the light of distant stars, and this smokiness of interstellar space, neglected by Shapley, made his distances somewhat too large. Correcting for interstellar absorption, we find the distance to the center of the Milky Way system to be about 30,000 light-years, a figure corroborated, incidentally, by studies of the dynamics of the galaxy—how it is held together without collapsing, and how it moves.

Our present picture of the Milky Way, then, is that of a flat pancake of stars, gas, and dust, some hundred million light-years across, in which the sun and planets are located about two-thirds of the way from the center to the edge, and which is partly embedded in a spherical array of globular clusters extending out some 30,000 light-years from the center. Now we can discuss what is beyond it.

Because they are extended surfaces, in contrast to the stars which appear as mere points of light in a telescope, the nebulae are some of the most interesting objects in the sky. From their form, their spectra, their positions, and, when established, their distances, two classes of nebulae can be distinguished: the galactic nebulae and the extragalactic nebulae. The former are, by and large, irregular in shape; they show the spectra (colors of light) emitted by low-density gases, and, as their name implies, they are found mostly near the Milky Way in the sky, at distances which place them well within that system. The extragalactic nebulae, on the other hand, have circular, elliptical, and spiral shapes, their spectra are like a mixture of star spectra, they are found predominantly in parts of the sky other than the Milky Way, and their distances have been found to be enormously larger than anything in the galaxy. This last point is the crux of the matter; how can we prove that these spiral and elliptical nebulae are beyond the confines of the Milky Way system?

The answer is simple if you have a large enough telescope. With the large telescopes in existence today, it is possible to photograph the separate stars and clusters in the largest (and closest) of the spirals, the great Andromeda nebula. Using the brightness method, and taking account of the nearby smokiness of our own Milky Way system, but assuming that space outside is transparent, Hubble has shown that the Cepheid variables and clusters in the Andromeda nebula must be about a million light-years away. Once the distances of another half dozen extragalactic nebulae were found by these methods, Hubble determined their average intrinsic luminosity (about 85 million times the sun's), and can now determine the distances to much more distant nebulae with the aid of this information. Using longer and longer exposures on faster and faster photographic plates with larger and larger telescopes, Hubble has pushed the confines of observable space out to over a billion light-years. In this vast volume he estimates there are some hundreds of millions of extragalactic nebulae, basing this estimate, of course, on a limited number of "sample" plates. Surveys now under way with the 20-inch refractor at the Lick Observatory and the 48-inch Schmidt camera at Palomar will cover somewhat smaller volumes more completely.

What can we find out about these distant objects so far beyond the Milky Way? It seems to me that the studies which have already been undertaken, and which are now under way, can be grouped in this manner, although there is some overlapping: First, we can find out more about *individual* extragalactic nebulae, their distances, sizes, masses, forms, and contents; second, as with any large class of objects, we can try to group them into further meaningful *subclasses*; third, we can study their *motions*, so far as they can be measured, and finally, their *numbers and distribution in space*. This last problem, literally the biggest in modern science, turns out to be linked with our fundamental notions of space and time.

Although it may seem simple, in principle, to determine the linear size of an object from its angular size and its distance, there are serious practical difficulties in the case of the nebulae. They have no clearly defined edges. Photographs of longer exposure show greater extensions, and there are reasons to believe that the Andromeda nebula, for example, is well over five times as large as what we can see in a telescope. The best photographs of this spiral show an angular extent corresponding to a diameter of about 40,000 light-years, at its distance of over 700,000 light-years. This is roughly the same size as the Milky Way system, which seems reasonable enough. (In fact, our picture of the Milky Way system has been developed partly by analogy to the form of spiral nebulae; in other words, it has long been in the back of astronomers' minds that the galaxy and the spirals are the same class

of objects.) But other spirals and the elliptical nebulae are found to have diameters much smaller than this; from 2,000 light-years to 10,000 light-years. We are thus forced to the conclusion that our galaxy is a giant among the spiral nebulae.

How can we "weigh" a nebula consisting of billions of stars? The method is similar to that for determining the mass of the sun; it depends upon measuring the motions of other masses in the vicinity. Since the outer stars in a nebula are attracted by the rest of the nebula, just as the planets are attracted by the sun, they would "fall" into the center were they not in motion in an orbit around that center. The motion is a measure of the gravitational pull of the nebula, which in turn is a measure of its mass. We can scarcely hope to see—or photograph—such motion as a change of position in the sky; at a distance of a million light-years a star would have to be moving at about 9,000 miles per second across the line of sight to change its position by even 1 second of arc in a century! Luckily there is a more sensitive method of measuring motion along the line of sight (toward or away from us) by its effect on the spectrum. This "Doppler effect," which may be deduced from basic notions of the nature of light, space, and time, consists of a slight change in color, toward the red for recession and toward the blue for approach, which can easily be detected with a spectrograph, if the light source has readily identified original colors in its spectrum. Early work at the Lowell Observatory and more recent work at the Lick Observatory have established from this effect that the spirals are rotating—at least, the ones viewed edge-on show more approach at one end than at the other. The amount of rotation of the outermost parts indicates a mass about 100 billion times that of the sun for the Andromeda nebula, and smaller masses, about 1 billion to 10 billion suns, for other nebulae. Similar reasoning leads us to expect that the Milky Way system is also rotating; this has been measured, and leads to a mass of over 200 billion suns. Again we find our own galaxy larger than the rest, which seems to leave us in a "preferred" position in the universe. Moreover, there are other reasons to feel dissatisfied with these small measured values of nebular masses, as will become apparent later on.

The form and content of the extragalactic nebulae have contributed largely to their classification. Although there are others, the most meaningful classification seems to be one proposed by Hubble. He recognized three broad classes, based on form alone: the elliptical nebulae, the spirals, and the barred spirals. Within each of these classes there is a continuous sequence from "early" to "late" types—from smaller, more compact forms to larger, looser forms in the spirals, and from circular to more elliptical forms in the elliptical nebulae. The terms "early" and "late" seem to have been unhappily

chosen, as it now appears that the "late" types, if anything, are younger in age. This conclusion is based by the German astrophysicist von Weizsäcker on dynamical arguments, by Baade and others on the content. Baade, at Mount Wilson, has superposed on Hubble's classification a distinction between two types of stellar population: Type I, associated with spiral arms, consists primarily of gas clouds and large, hot, blue stars which are thought, from considerations of stellar evolution to be young; type II population, associated with the elliptical nebulae and the cores of spirals, consists primarily of cooler stars, which may be quite as old as the earth and sun—a good 3 billion years. Hubble's three classes can be arranged in a kind of sequence, from the globular (circular appearing) elliptical nebulae, through the more and more elliptical types, through a transition type neither elliptical nor spiral, and then, in two parallel "branches," through the later and later types of spirals, both normal and barred. If the more recent ideas are correct, spiral evolution is taking place in the reverse direction; late-type spirals are collapsing to the final stage of globular nebulae.

One aspect of the content of extragalactic nebulae has received but scant attention until recently. Just as in our own galaxy, there is interstellar gas and dust in the other nebulae. The dust shows up as dark streaks on photographs; the gas emits light of the characteristic colors of hydrogen, oxygen, nitrogen, and other gases. In the extragalactic nebulae we have an excellent opportunity to study the distribution and physical conditions of these interstellar gases, and work now in progress at the McDonald Observatory is directed to this end.

We have already seen how one component of the motion (the radial velocity) of nebulae can be measured by the Doppler effect, and how their distances can be estimated by the brightness method. In 1925, Hubble and Humason at the Mount Wilson Observatory noted a correlation between these two, in the sense that velocity of recession for nebulae on all sides of us increases with increasing distance. The later work of Hubble and Humason has shown a remarkable relation which holds as far as the spectra of nebulae can be observed: the velocity of recession on every side is proportional to the distance, and increases about 100 miles per second in each million light-years.

At first sight, this observation seems to leave us—or our galaxy—in a central and highly repelling position, with all the rest of the universe "running away from us." A moment's reflection shows, however, that the "velocity-distance law" implies a symmetrical view from any other nebula; an observer there, considering himself "at rest," would see the others "running away" from him, and with velocities proportional to their distances. As for explanation of this strange behavior,

there are several. The most easily visualized is based on the simple assumption that a cosmic explosion started the nebulae moving apart from a common starting point with speeds which have since remained roughly constant, and that the fastest moving ones have naturally got the farthest. From this simple concept, together with the rate of increase of recessional velocity with distance, we can readily compute that the explosion must have taken place some 2 billion years ago, a figure in fair agreement with the age of the earth determined from quite different data (radioactive decay in minerals). However, there are further complications which cast doubt on this simple explanation.

There are so many nebulae that a plot of each one's position in space would be literally an endless task. The best means of representing their distribution in space so far devised has been to count, or estimate, the numbers out to various distances. For instance, a survey by Shapley and Ames at Harvard showed over a thousand nebulae actually brighter than "thirteenth magnitude" (visible in a 6- or 7-inch telescope), another by Mayall at the Lick Observatory shows an estimated 9 million over the whole sky brighter than "nineteenth magnitude" (corrected for obscuration by local interstellar dust) from sample plates taken with the 36-inch reflector, and two other sampling surveys by Hubble with the 100-inch telescope at the Mount Wilson Observatory indicate that there are an estimated 70 million brighter than the "twentieth magnitude"—as faint as the 100-inch telescope can conveniently photograph. From the average intrinsic brightnesses of nebulae we can convert these figures to (roughly): 2,000 within 13 million light-years, 9,000,000 within 200 million light-years, and 70,000,000 within 450 million light-years.

These numbers are about what we would expect if the nebulae were *evenly* distributed, about 2 in each 10-billion-billion cubic light-years. The numbers would then increase with the cube of the distance, since the volume of a sphere is proportional to the cube of its radius. The two deepest surveys, however, depart slightly from the cube law, indicating a thinning out of nebulae the farther we go from our galaxy. Now it has been repugnant to astronomers since the time of Copernicus to consider ourselves "at the center," as this thinning out would imply; hence a number of efforts have been made to interpret this last result, tentative though it may be, in such a way that no "center" is necessary. A number of difficulties arise; for instance, we are seeing the distant nebulae not where they are now, but where they were 13 to 450 million years ago, the time required for their light to reach us. Their intrinsic brightness, too, may not be constant in time. And it is certain that their light is so changed toward redder color by the Doppler effect that a correction must be made for its reduced power to blacken the

photographic plate. What is more, a receding source should theoretically be fainter than the same source of light at rest.

Using the best data available in 1935, Hubble and Tolman concluded that these deepest surveys can be understood if space itself is "curved," somewhat like a two-dimensional surface can be curved into the form of a sphere. Just as there is not as much area in a circle on the surface of a sphere as there is within a circle of the same radius on a flat surface, so, too, there would be less "room" in "curved space" than in "flat space," as we normally conceive it, for spirals at great distances from us. This conclusion was inspired by Einstein's General Theory of Relativity, which ascribes what we normally call gravitation to a kind of curvature of space; in other words, space is expected to be curved by the mass of matter contained in it. Unfortunately the curvature of space necessary to explain Hubble's counts of the nebulae is very large—corresponding to a radius of only 500 million light-years or so, which implies a very large amount of matter, not at all in agreement with the observed space density of spirals and the (small) masses measured from their rotations.

This is the impasse we have reached in our attempt to understand the universe beyond the Milky Way. It may be removed by improving the observational data; by better measurement of the masses of spirals, including the faint outer parts, as we are trying to do at the McDonald Observatory; by finding evidence for matter between the spirals; by improving the correction for the Doppler effect as Stebbins and Whitford of Wisconsin are doing in their color work at Mount Wilson; or by better and more complete surveys of the nebulae which are soon to be expected from the 48-inch Schmidt telescope and 200-inch telescope at Palomar. Or it may be removed by some new line of theoretical reasoning such as the Kinematical Relativity of Milne, in England, or by taking account of the clustering of nebulae, in a revision of Tolman's calculations, as now being undertaken by Omer at Chicago. Probably the solution will be found through some combination of these, but I have no doubt that, when it is reached, some even larger problem will be found to take its place.

THE LUMINOUS SURFACE AND ATMOSPHERE OF THE SUN¹

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[With 3 plates]

There is no process in nature more important to us than the radiation of light and heat from the surface of the sun. The famous American astronomer Charles E. St. John, of the Mount Wilson Observatory, once expressed this in a lecture² in the following words:

Not only is the motion of the earth in space controlled by the masterful sun, but what is more directly evident, the sun is the source of practically all our light and heat, without which life, as we know it, could not exist upon the earth. Someone has said that if the earth were cut off from all solar radiation for a single month, all life would be extinguished and the world become a frozen waste. It is not so evident, but as clearly true, that the energy stored in wood, coal, oil, and gas has come to us from the sun. Under the influence of sunlight, particularly of the red and blue components, the carbon dioxide of the atmosphere is taken in by the leaves of trees and plants and acted upon to form the complex constituents of plant growth, mainly compounds of carbon with hydrogen, oxygen, and nitrogen. Their chemical transformation requires the absorption of energy which is accumulated and stored in these compounds, to be released and again transformed when they are burned rapidly in ordinary combustion, or slowly in our own bodies. Every heart beat, every breath we take, every thought, and every act performed draws its working power from the accumulated solar energy stored up in plant and animal growth. The transformation of solar energy in plant growth takes place in the leaves under the action of sunlight upon the green coloring matter, the chlorophyll. As heat engines plants cannot be considered efficient, transforming as they do only 1 or 2 percent of the solar energy falling upon their leaves, but the energy supplied is enormous; plants work continually during growth and store up energy in permanent form; these are favorable conditions and result in tremendous advantages for man. The energy of coal has waited for his touch many millions of years and what, if any, escapes his wasteful use will endure uncounted millions yet without loss of its potential energy. The energy of the sun is stored in the water lifted into the atmosphere by the sun's power and carried by wind-driven clouds to higher regions, whence it falls as rain or snow, ever renewing the reservoirs and so rendering them a practically exhaustless source of power.

¹ Seventeenth James Arthur lecture, given under the auspices of the Smithsonian Institution on April 6, 1950.

² The Adolfo Stahl Lectures in Astronomy, San Francisco, 1919.

The exact amount of solar radiation is known mainly from the measurements made by the observers of the Smithsonian Institution, Dr. C. G. Abbot and his collaborators, at Washington, D. C., and at various stations on the globe. On each square centimeter of a sphere whose radius is the mean distance of the earth from the sun, falls 1.9 calories per minute. The distance of the sun from the earth is 93 million miles, and from this we can readily find the enormous amount of energy released by a square centimeter of the surface of the sun, about 1,500 calories per second. By the laws of radiation we may then calculate the effective temperature of the solar surface to be about 5,700°. The mass of the sun is 332,000 times the mass of the earth, and we may conclude that on the average each gram of the solar mass loses 1.4 calories per year. During a few thousand million years, which we assume to be the age of the sun, the amount becomes tremendous.

There have been different theories as to the origin of the energy output of the sun. We have had mechanical theories which assume that the source of energy is the kinetic energy of meteorites captured by the sun, or the potential energy lost by the shrinking of the entire body of the sun in a process of contraction. We know now beyond doubt that the main source of energy is of inner-atomic origin. In the interior of the sun the temperature and density must increase immensely toward the center. The mass of the interior consists mainly of hydrogen and helium in fairly equal amounts, whereas the amount of all other elements together is only about 12 percent of the entire mass. All elements will be in a high stage of ionization. The ionized hydrogen atoms, or protons, will fairly often hit each other, as well as the nuclei of other atoms, and if the impact carries sufficient energy a nuclear reaction may take place.

There is in the sun a central core of a temperature of about 25 million degrees, which is sufficient to produce certain nuclear reactions that release a great amount of energy. The intermediate region between the core and the surface of the sun has a great power of absorption on the stream of light generated in the central regions. This light is of very short wavelength, corresponding to X-rays and γ -rays. In the regions close to the surface the density decreases rapidly outward, till we reach the photospheric layers, from which we receive light directly. The sun has no fixed boundary, and the decrease of density of the gaseous layers is quite continuous. From the photospheric layers there is a continuous transition to the sun's "atmosphere," which we define as the layers where the absorption lines in the solar spectrum are formed.

The upper part of the sun's atmosphere is the chromosphere. It has in general a very irregular structure, and it is from the chromo-

sphere that the solar prominences extend widely outward, in a great variety of sizes and shapes. Outside the chromosphere the solar corona extends in its streamlined structure resembling the lines of force about a magnetized sphere. As we shall see later, the temperature in the high solar atmosphere increases outward, reaching very high values in the thin matter of the corona.

The nuclear processes responsible for the release of energy in the central regions of the sun are mainly the combination of two protons into a nucleus of heavy hydrogen, deuterium, and a certain cycle of atomic permutations involving nuclei of carbon, nitrogen, and oxygen, which is maintained by impacts between protons and the nuclear isotopes C^{12} and C^{13} of carbon and N^{14} and N^{15} of nitrogen. The net result of the cycle, which has been demonstrated especially by H. A. Bethe, is the combination of four hydrogen atoms into one atom of helium. It has been proved that the two processes mentioned are entirely sufficient to explain the rate of radiation of the sun. The total lifetime of the sun, during which the main mass of hydrogen is transformed into deuterium and helium, has been estimated to be of the order of magnitude of 10 thousand million years. The sun is an enormous atomic pile, and the same must be true for the stars in general, though the atomic processes are not necessarily the same for stars of all types.

The energy released from the core paves its way to the surface of the sun by a very complicated process of successive absorption and emission and is steadily transformed in this way into radiation of a successively lower temperature, until it reaches the photospheric layers at the surface, which have an effective temperature of $5,713^{\circ}$.

The main part of the mass of the sun is in radiative equilibrium, which means that each element of the mass absorbs and emits the same amount of energy. An exception is probably the central core, where the rapid increase of the rate of release of inner-atomic energy, when we approach the center, makes conditions unstable so that there will occur a turbulent motion with steady interchange of matter between different levels. At the surface of the sun the conditions of radiative equilibrium still prevail. The well-known phenomenon that the intensity of the solar disk decreases from the center to the edge, and much more strongly in violet than in red light, is explained quantitatively to a high degree of accuracy by the theory of radiative equilibrium.

It is evident, however, that the conditions of equilibrium are not perfect in the surface layers of the sun. The solar surface, when viewed under great magnification, shows a complicated network of fine grains, a phenomenon that is called the granulation of the solar surface. The grains have a diameter of the order of 500 kilometers

and a duration of a few minutes. The granulation bears witness of the existence of turbulent gaseous layers in the photosphere.

Local disturbances of the equilibrium are the sunspots and all the phenomena associated with the formation of the spots. The frequency of the spots follows the well-known 11-year period. In the beginning of a new cycle the spots appear in high heliographic latitude, and then, as the cycle proceeds, the spots appear closer and closer to the Equator. The electromagnetic fields associated with sunspots are of extremely great interest. The spots often appear in pairs of opposite magnetic polarities, or in groups in which a line may be drawn between spots of opposite polarities. During a certain cycle there is a fixed rule according to which the poles follow each other in the direction of rotation. If a south pole follows a north pole in the northern hemisphere, the opposite order will hold in the southern hemisphere. From one cycle to the next the order changes in both hemispheres. This shows that the true sunspot cycle embraces two 11-year periods, thus 22 years.

The most important instrument for investigating the surface of the sun is the spectroheliograph. In this instrument, which was designed over 50 years ago independently by G. E. Hale and H. Deslandres, the solar surface is photographed in light of a very small interval in wavelength. Most often the spectroheliograms are taken in light which is contained within a certain absorption line in the solar spectrum. The color band of the solar spectrum is not a continuous one, but is broken by an immense number of absorption lines, the Fraunhofer lines, which correspond to the characteristic lines of the atoms of various elements that are present in the solar atmosphere. The interpretation of these lines as belonging to various elements opened up the field of solar physics. About 25 years ago H. N. Russell showed how the intensity of the lines allow us to draw conclusions as to the amounts in which the various elements occur in the atmosphere of the sun. Usually the spectroheliograms are taken in one of the heavy lines of ionized calcium, the Fraunhofer lines H and K, or in the hydrogen lines, for instance the red $H\alpha$. The photographs in H or K show the wide and bright "flocculi," or chromospheric faculae, of ionized calcium which are often conspicuously dense about the sunspots. Spectroheliograms in the hydrogen lines are of very special importance. They show often narrow, bright areas which develop rapidly, often within a few hours, the so-called solar "flares." These eruptions are often connected with disturbances in the terrestrial magnetism and in the ionospheric layers, and are often accompanied by the appearance of bright aurorae. The disturbances in the ionosphere often cause interruptions in the transmission of radio waves.

The spectroheliograms in $H\alpha$ show narrow, dark "filaments" of

hydrogen which have often an enormous extension. When the spectroheliograms are extended over the limb of the sun, we find that these filaments are continued as bright prominences outside of the limb. The development of the prominences have been studied with great advantage cinematographically, especially by B. Lyot, R. McMath, and D. H. Menzel, with a great acceleration of the time scale. The mechanism underlying the formation and decay of prominences offers a great many questions which are as yet unsolved.

The study of the solar corona was earlier confined to the total eclipses of the sun. The French astronomer B. Lyot, of Meudon, has constructed an instrument, "the coronagraph," by which the inner parts of the corona may be photographed in full daylight. The spectrum of the corona is mainly continuous, owing to a reflection of sunlight by free electrons, but shows also certain emission lines. The identification of these lines has been singularly difficult. At last the Swedish physicist B. Edlén solved the riddle, and showed that the lines were due to extremely highly ionized atoms. The intense green line is due to iron that has lost 13 electrons. The corresponding temperature of the corona is extremely high, several hundred thousand degrees. Several theories have been advanced to explain why the corona has such a high temperature, but there are still many questions in this connection that have not yet been answered.

Though the prominences, as well as the corona, may now be studied in full daylight, the total eclipses of the sun still play a great part in the study of the physics of the sun. Moreover, an exact timing of the occurrence of an eclipse on various places along the eclipse track may give important information about the exact shape of our own globe.

Ancient eclipses recorded in the countries about the Mediterranean have proved to be of importance in answering the question of the secular increase in the time of revolution of the earth. We may reconstruct by modern theory the track of the eclipse, on the assumption that our unit of time, the sidereal revolution of the earth, is unchanged. The difference between the old observations and the modern computations has enabled astronomers to draw the conclusion that there is an increase in the time of revolution of the earth of the order of one-thousandth of a second per century. The change is due to the friction of the tidal wave in the ocean, especially in shallow waters close to certain coast lines.

To the astrophysicist the beginning and end of a total eclipse are of special interest. When the last glimpse of the intensity-radiating surface of the sun vanishes, the spectrum changes character, and instead of the absorption spectrum of the solar disk we get the emission spectrum of the chromosphere. This so-called "flash spectrum"

consists of a series of bright lines, and appears as an inversion of the ordinary solar spectrum. This spectrum is of very great importance for the study of the extreme layers of the sun, and it has been observed very completely, especially by W. W. Campbell, of the Lick Observatory, and by S. A. Mitchell, of the Leander McCormick Observatory. S. A. Mitchell, D. H. Menzel, and R. Wildt have drawn elaborate conclusions as to the physical constitution of the sun's outer layers from studies of the flash spectrum. In these studies spectra of fairly large dispersion have been used.

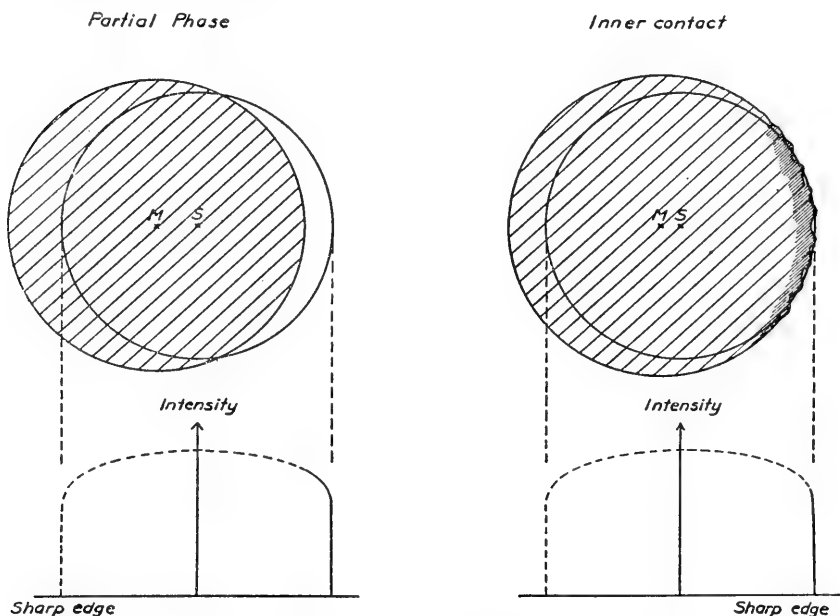


FIGURE 1.—Schematic picture of partial eclipse and of inner contact between the limbs of the sun and moon. The centers of sun and moon are indicated by S and M. The distribution of intensity along the radius of the solar disk is indicated below.

For a photometric study of the rapid change in the spectrum at the beginning and end of a total eclipse considerably smaller dispersion may be used, and in this case it is of advantage to photograph the spectrum with a motion-picture camera. A rather successful attempt at a cinematographic study of the flash spectrum was made in Sweden by O. Wiberg and myself at the total eclipse in 1927. At the same eclipse the Polish astronomer T. Banachiewicz developed a method of determining very exactly the times of contact between the limbs of the sun and moon by direct cinematography of the sun at the beginning and end of the partial and total phases of the eclipse and by a study of the details of the lunar limb which produce the

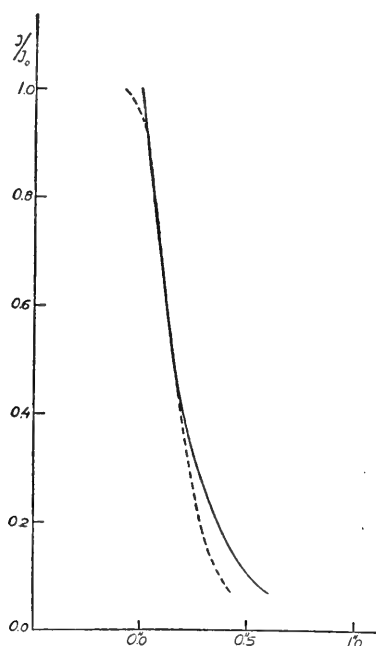


FIGURE 2.—The decrease of intensity with increasing height at the extreme limb obtained from the moving-picture record. Abscissa is height in seconds of arc, ordinate is the light intensity in the blue spectral region expressed in an arbitrary unit. The dotted curve has been drawn according to theoretical results by R. Wildt.

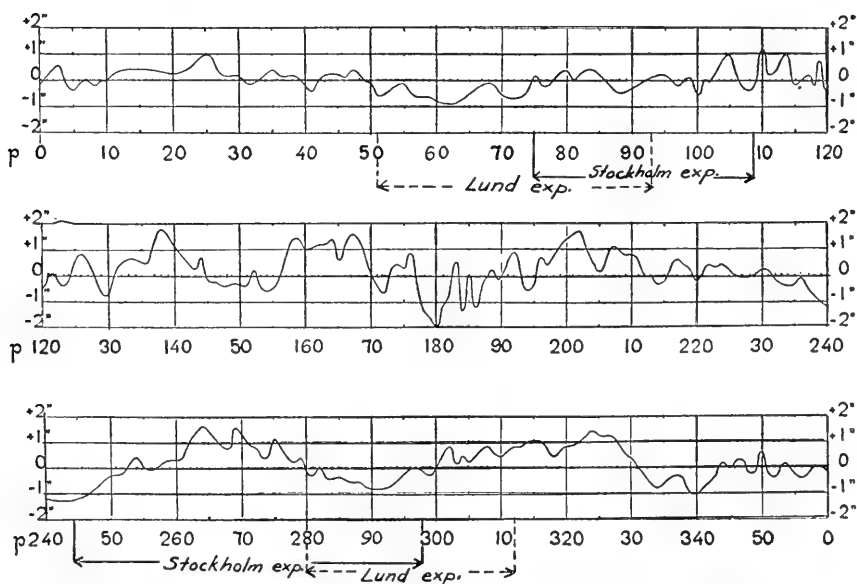


FIGURE 3.—Lunar contour predicted from Hayn's maps for the eclipse of July 9, 1945.

so-called "Baily's beads" at the beginning and end of the total eclipse. The cinematography of the flash spectrum may serve the same purpose, and has even some advantage because of the exact spectrophotometric methods that may be applied in this case.

If the contacts may be defined and measured accurately enough, observations of the contacts at various points along the track of the eclipse may give very exact information as to the distances between the points of observation on the surface of the earth. The information obtained has thus a direct geodetic interest. The first attempt to make a geodetic application of the determination of eclipse contacts was made by Banachiewicz, and after him the idea was taken up with very great interest by the Finnish astronomer and geodesist,

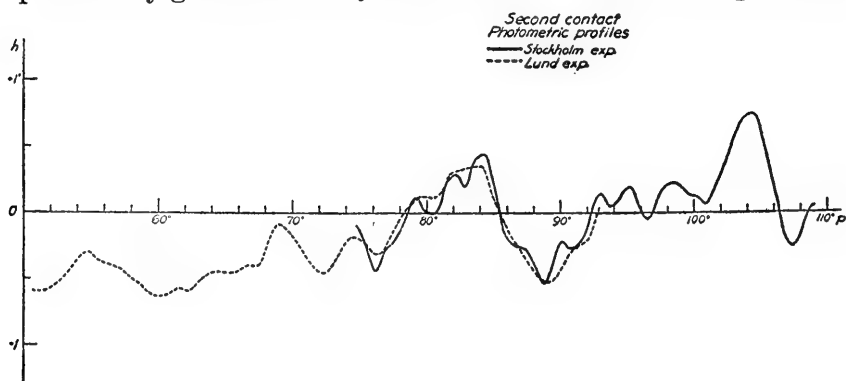


FIGURE 4.—The lunar contour determined photometrically from the records of the flash-spectrum according to the results from the Stockholm expedition (full-drawn curve) and the Lund expedition (dotted curve). Second contact.

I. Bonsdorff. Attempts to apply the cinematographic methods of contact determination have been made by Finnish and Swedish eclipse expeditions using direct cinematography of the solar disk, as well as cinematography of the flash spectrum.

At the eclipse in northern Sweden in 1945 the three Swedish observatories of Lund, Stockholm, and Uppsala had the cinematography of the flash spectrum on their programs, with elaborate instrumental equipments. The exact timing of each exposure on the film was made by recording the exposures together with time signals by means of a cathode-ray oscillograph. Very appropriate instruments of this kind were designed by K. G. Malmquist, H. Norinder, W. Stoffregen, and L. Stigmark. The cinematographic film was photometrically standardized by means of a sensitometer.

The photometric measurements allow us to determine the rate of decrease of the intensity of the continuous spectrum at the extreme limb of the sun, i. e., the "sharpness" of the limb. It has been found

by H. Kristenson and myself to amount to about five magnitudes per second of arc. A certain arbitrary layer may be assumed to define the "photosphere." When the decrease of intensity with height over the photosphere is known, each measurement of the intensity of the continuous spectrum may be converted into height over the photosphere. The measurements on various spectral images on the film therefore give the profile of the lunar contour in relation to the photosphere. In this way each spectral image links together the solar and lunar limbs with extreme accuracy and we may define and measure the contact with a mean error of only a few hundredths of a second. As intermediary, when defining the contact, F. Hayn's map of the lunar contour for different degrees of libration may be used with advantage.

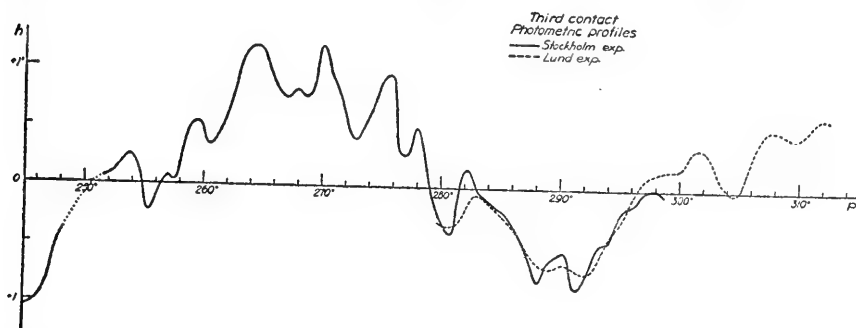


FIGURE 5.—The lunar contour determined photometrically from the records of the flash spectrum according to the results from the Stockholm expedition (full-drawn curve) and the Lund expedition (dotted curve). Third contact.

The comparison of contours with respect to the photosphere for points along the eclipse track enables us to find the difference between the times at which a given contact occurs at different places with a very great accuracy. If E_1 and E_2 (fig. 6) are two points at which contacts are being observed, and if we know the motion of the moon and the distance between the earth and the moon, the difference in time for the two places will allow us to determine the true distance E_1'/E_2 between the two places.

At the total eclipse of May 20, 1947, an attempt to apply the cinematographic methods for contact determinations was made by expeditions sent by the Finnish Geodetic Institute and by the Geographical Survey Office in Sweden, in collaboration with the Swedish observatories of Lund, Stockholm, and Uppsala, to Brazil and to French Togoland and the Gold Coast. On account of bad weather at the place of the Swedish Brazil expedition, cinematography of the flash spectrum could only be carried through on the African side.

The next eclipse that will allow a connection in this way between America and Europe occurs on June 30, 1954.

Observations of this kind evidently connect the motion of the moon, the distance of the moon, and distances on the earth in a very interesting way, which may refine our knowledge concerning our own globe, as well as concerning its satellite, the moon.

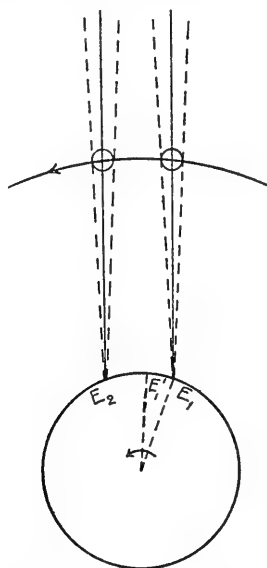
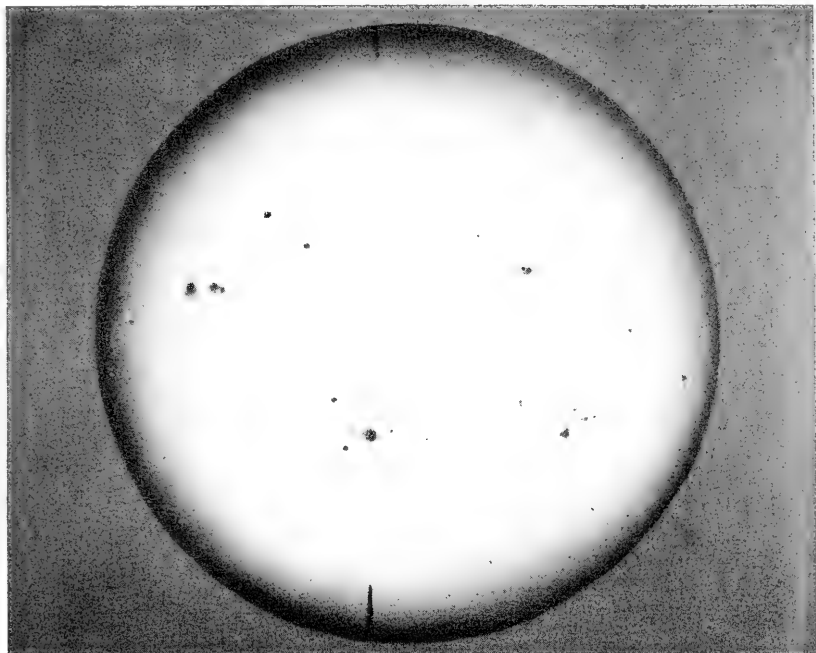
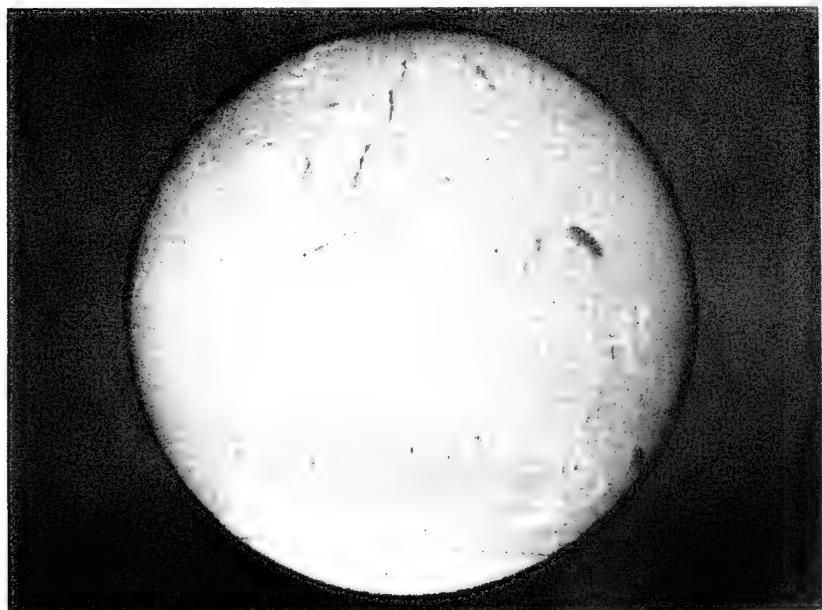


FIGURE 6.—Schematic picture showing measurement of distances on the earth by contact determinations at an eclipse. If the contacts are observed when the cone of the lunar shadow points at E_1 and E_2 , the distance on the earth corrected for the rotation of the earth in the time interval between the two observations is $E_1'E_2$.

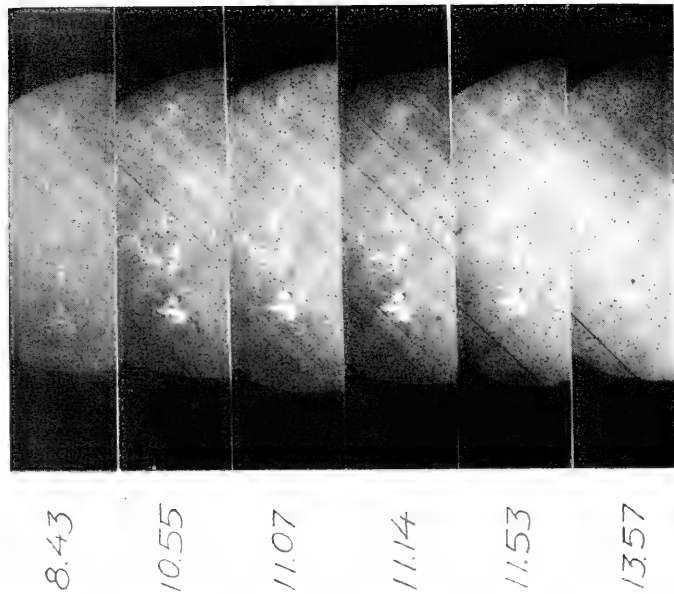
It is typical for science to proceed in successive approximations toward increased knowledge. New connections between observed phenomena offer the possibility of penetrating the secrets of nature in greater and greater detail. This is true also for the wonderful mechanism of our solar system. Even if the astronomer nowadays is often carried by his ambition to study distant galaxies, it is still true that some of the deepest secrets of nature that can come within the working field of the astronomer lie hidden within the limits of our own solar system, and, above all, in the sun itself, the patient donor of all good gifts to our planet and to mankind.



1. Photograph of the sun in ultraviolet light, May 12, 1948, showing spot groups, solar faculae, and the general decrease of intensity from center to limb. Stockholm Observatory.



2. Spectroheliogram in the hydrogen line $H\alpha$ taken with spectroheliograph constructed by Y. Öhman, Stockholm Observatory, April 3, 1949. Dark filaments, actually prominences, and several bright areas are shown.



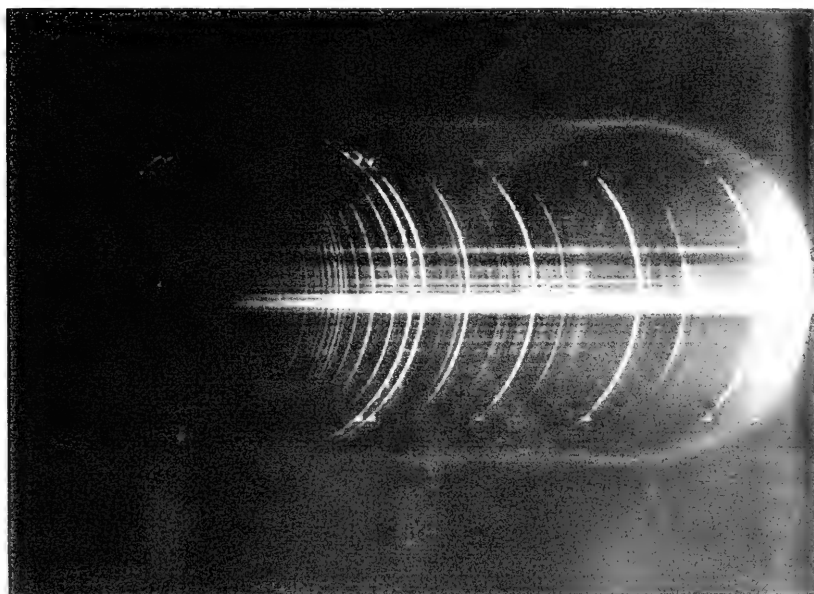
1. Solar flare photographed by Y. Öhman at the Stockholm Observatory on May 10, 1950. The times of the photographs are indicated and show the rapid development and decay of the flare.



2. Prominence connected with spot group, May 25, 1948. The picture of the spot group has been taken 3 days later, when the group has moved on the disk by the rotation of the sun. L. Dahlmark, Stockholm Observatory.



1. Prominence photographed on November 26, 1948, by Y. Öhman, Stockholm Observatory.



2. Enlarged reproduction of the flash spectrum from one picture of the cinematographic film obtained on July 9, 1945, by the Stockholm Observatory expedition at Brattås, Sweden. The spectrum of the solar atmosphere appears as a series of emission lines. The strongest lines are those of hydrogen, beginning at the limit of the Balmer series in the ultraviolet (extreme left), to the red $H\alpha$ line (right-hand limit), and the H and K lines of calcium, a conspicuous pair on the left-hand side, and the lines of helium, of which the strongest line is the D_3 line to the left of $H\alpha$. The continuous spectrum in the middle is a part of the extreme "photospheric" layer shining through a valley on the moon.

WHAT IS AN ELEMENTARY PARTICLE?¹

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1. A PARTICLE IS NOT AN INDIVIDUAL

Atomism in its latest form is called quantum mechanics. It has extended its range to comprise, besides ordinary matter, all kinds of radiation, including light—in brief, all forms of energy, ordinary matter being one of them. In the present form of the theory the “atoms” are electrons, protons, photons, mesons, etc. The generic name is elementary particle, or merely particle. The term “atom” has very wisely been retained for chemical atoms, though it has become a misnomer.

This essay deals with the elementary particle, more particularly with a certain feature that this concept has acquired—or rather lost—in quantum mechanics. I mean this: That the elementary particle is not an individual; it cannot be identified, it lacks “sameness.” The fact is known to every physicist, but is rarely given any prominence in surveys readable by nonspecialists. In technical language it is covered by saying that the particles “obey” new-fangled statistics, either Einstein-Bose or Fermi-Dirac statistics. The implication, far from obvious, is that the unsuspected epithet “this” is not quite properly applicable to, say, an electron, except with caution, in a restricted sense, and sometimes not at all. My objective here is to explain this point and to give it the thought it deserves. In order to create a foil for the discussion, let me summarize in sections 2–5 what we are usually told about particles and waves in the new physics.

2. CURRENT VIEWS: THE AMALGAMATION OF PARTICLES AND WAVES

Our image of the material world had been made up of two kinds of “fittings”—waves and particles. The former were instanced mainly, if not exclusively, by Maxwell’s waves of electromagnetic energy, comprising such as are used in radio, light, X-rays, and gamma-rays. Material bodies were said to consist of particles. One

¹ Reprinted by permission from *Endeavour*, vol. 9, No. 35, July 1950.

was also familiar with jets of particles, called corpuscular rays, such as cathode rays, beta-rays, alpha-rays, anode rays, etc. Particles would emit and absorb waves. For instance, cathode rays (electrons), when slowed down by colliding with atoms, emit X-rays. The distinction between particles and waves was, however, considered as clear-cut as that between a violin and its sound. An examinee who alleged cathode rays to be waves, or X-rays to be jets of particles, would have got very bad marks.

In the new setting of ideas the distinction has vanished, because it was discovered that all particles have also wave properties, and vice versa. Neither of the two concepts must be discarded; they must be amalgamated. Which aspect obtrudes itself depends not on the physical object, but on the experimental device set up to examine it. A jet of cathode rays, for example, produces in a Wilson cloud chamber discrete tracks of water droplets—curved tracks if there is a magnetic field to deflect the electrons, otherwise straight alignments of droplets. We cannot but interpret them as traces of the paths of single electrons. Yet the same jet, after crossing a narrow tube placed at right angles to it and containing crystal powder, will produce on a photographic plate at some distance behind the tube a pattern of concentric circles. This pattern can be understood in all its details when looked upon as the interference pattern of waves, and in no other way. Indeed, it bears a close resemblance to similarly produced X-ray patterns.

The suspicion arises: are the conical jets that impinge on the photographic plate and form the pattern of circles really cathode rays; are they not perhaps secondary X-rays? The suspicion has to be dismissed, for the whole system of circles can be displaced by a magnet, while X-rays cannot; moreover, by putting a lead screen with a small hole in it in the place of the photographic plate, a jetlet can be isolated from one of the conical jets and made to display any of the typical particle characters of cathode rays; it will produce discrete tracks in a cloud chamber; bring about discrete discharges in a Geiger-Müller counter; and charge up a Faraday cage in which it is intercepted.

A vast amount of experimental evidence clinches the conviction that wave characteristics and particle characteristics are never encountered singly, but always in a union; they form different aspects of the same phenomenon, and indeed of all physical phenomena. The union is not a loose or superficial one. It would be quite unsatisfactory to consider cathode rays to consist both of particles and of waves. In the early days of the new theory it was suggested that the particles might be singular spots within the waves, actually singularities in the meaning of the mathematician. The white crests on a moderately rough sea

would be a fairly adequate simile. The idea was very soon abandoned. It seems that both concepts, that of waves and that of particles, have to be modified considerably, so as to attain a true amalgamation.

3. CURRENT VIEWS: THE NATURE OF WAVES

The waves, so we are told, must not be regarded as quite real waves. It is true that they produce interference patterns—which is the crucial test that in the case of light had removed all doubts as to the reality of the waves. However, we are now told that all waves, including light, ought rather to be looked upon as “probability waves.” They are only a mathematical device for computing the probability of finding a particle in certain conditions, for instance (in the above example), the probability of an electron hitting the photographic plate within a small specified area. There it is registered by acting on a grain of silver bromide. The interference pattern is to be regarded as a statistical registration of the impinging electrons. The waves are in this context sometimes referred to as guiding waves—guiding or directing the particles on their paths. The guidance is not to be regarded as a rigid one; it merely constitutes a probability. The clear-cut pattern is a statistical result, its definiteness being due to the enormous number of particles.

Here I cannot refrain from mentioning an objection which is too obvious not to occur to the reader. Something that influences the physical behavior of something else must not in any respect be called less real than the something it influences—whatever meaning we may give to the dangerous epithet “real.” It is certainly useful to recall at times that all quantitative models or images conceived by the physicist are, epistemologically, only mathematical devices for computing observable events, but I cannot see that this applies more to, say, light waves than to, say, oxygen molecules.

4. CURRENT VIEWS: THE NATURE OF PARTICLES (UNCERTAINTY RELATION)

As regards the modification required in the concept of a particle, the stress is on Heisenberg’s uncertainty relation. The so-called classical mechanics hinged on Galileo’s and Newton’s discovery that the thing which in a moving body is determined at any instant by the other bodies in its environment is only and precisely its acceleration, or, in mathematical terms, the second derivatives with respect to time of the coordinates. The first derivatives, commonly called the velocity, are therefore to be included in the description of the momentary state of the body, together with the coordinates themselves which label its momentary place in space or “whereness” (or ubiety, to use an antiquated but convenient word). Thus, to describe the momen-

tary state of a particle, two independent data were required: its coordinates and their first time derivatives, or ubiety and velocity. According to the new theory less is required, and less is obtainable. Either of the two data can be given with arbitrary accuracy, provided that no store is set on the other, but both cannot be known together with absolute precision. One may not even conceive of both as having absolutely sharp values at the same instant. They mutually blur each other, as it were. Broadly speaking, the product of the latitudes of their respective inaccuracies cannot be reduced below a fixed constant. For an electron, this constant happens to be about 1 if the units centimeter and second are used. Thus, if the velocity of an electron is considered sharp with a latitude of only 1 centimeter per second, its location has to be considered as blurred within the latitude of 1 centimeter. The strangeness does not lie in the mere existence of inaccuracies, for the particle might be a thing of vague and changeable extension, within which slightly different velocities prevailed at different spots. Then, however, a sharp location or ubiety would probably entail a sharply defined velocity and vice versa. Actually it is just the other way round.

5. CURRENT VIEWS: THE MEANING OF THE UNCERTAINTY RELATION

Two links connect this strange and certainly very fundamental statement to other parts of the theory. It can be arrived at by declaring that a particle is equivalent to its guiding wave, and has no characteristics save those indicated by the guiding wave according to a certain code. The code is simple enough. The ubiety is indicated by the extension of the wave, the latitude in the velocity by the range of wave numbers. "Wave number" is short for reciprocal of the wavelength. Each wave number corresponds to a certain velocity proportional to it. That is the code. It is a mathematical truism that the smaller a wave group, the wider is the (minimum) spread of its wave numbers.

Alternatively, we may scrutinize the experimental procedure for determining either the ubiety or the velocity. Any such measuring device implies a transfer of energy between the particle and some measuring instrument—eventually the observer himself, who has to take a reading. This means an actual physical interference with the particle. The disturbance cannot be arbitrarily reduced, because energy is not exchanged continuously but in portions. We are given to understand that, when measuring one of the two items, ubiety or velocity, we interfere with the other the more violently the higher the precision we aim at. We blur its value within a latitude inversely proportional to the latitude of error allowed in the first.

In both explanations the wording seems to suggest that the uncertainty or lack of precision refers to the attainable knowledge about a particle rather than to its nature. Indeed, by saying that we disturb or change a measurable physical quantity we logically imply that it has certain values before and after our interference, whether we know them or not. And in the first explanation, involving the wave, if we call it a guiding wave how should it guide the particle on its path, if the particle has not got a path? If we say the wave indicates the probability of finding the particle at A, or at B, or at C—this seems to imply that the particle is at one, and one only, of these places; and similarly for the velocity. (Actually the wave does indicate both probabilities simultaneously, one by its extension, the other by its wave numbers.) However, the current view does not accept either ubiquity or velocity as permanent objective realities. It stresses the word “finding.” Finding the particle at point A does not imply that it has been there before. We are more or less given to understand that our measuring device has brought it there or “concentrated” it at that point, while at the same time we have disturbed its velocity. And this does not imply that the velocity “had” a value. We have only disturbed or changed the probability of finding this or that value of the velocity if we measure it. The implications as to “being” or “having” are misconceptions, to be blamed on language. Positivist philosophy is invoked to tell us that we must not distinguish between the knowledge we can obtain of a physical object and its actual state. The two are one.

6. CRITICISM OF THE UNCERTAINTY RELATION

I will not discuss here that tenet of positivist philosophy. I fully agree that the uncertainty relation has nothing to do with incomplete knowledge. It does not reduce the amount of information attainable about a particle as compared with views held previously. The conclusion is that these views were wrong and we must give them up. We must not believe that the completer description they demanded about what is really going on in the physical world is conceivable, but in practice unobtainable. This would mean clinging to the old view. Still, it does not necessarily follow that we must give up speaking and thinking in terms of what is really going on in the physical world. It has become a convenient habit to picture it as a reality. In everyday life we all follow this habit, even those philosophers who opposed it theoretically, such as Bishop Berkeley. Such theoretical controversy is on a different plane. Physics has nothing to do with it. Physics takes its start from everyday experience, which it continues by more subtle means. It remains akin to it, does not transcend it generically, it cannot enter into another realm. Discoveries in physics cannot in

themselves—so I believe—have the authority of forcing us to put an end to the habit of picturing the physical world as a reality.

I believe the situation is this. We have taken over from previous theory the idea of a particle and all the technical language concerning it. This idea is inadequate. It constantly drives our mind to ask information which has obviously no significance. Its imaginative structure exhibits features which are alien to the real particle. An adequate picture must not trouble us with this disquieting urge; it must be incapable of picturing more than there is; it must refuse any further addition. Most people seem to think that no such picture can be found. One may, of course, point to the circumstantial evidence (which I am sorry to say is not changed by this essay) that in fact none has been found. I can, however, think of some reasons for this, apart from the genuine intricacy of the case. The palliative, taken from positivist philosophy and purporting to be a reasonable way out, was administered fairly early and authoritatively. It seemed to relieve us from the search for what I should call real understanding; it even rendered the endeavor suspect, as betraying an unphilosophical mind—the mind of a child who regretted the loss of its favorite toy (the picture or model) and would not realize that it was gone forever. As a second point, I submit that the difficulty may be intimately connected with the principal subject of this paper, to which I shall now turn without further delay. The uncertainty relation refers to the particle. The particle, as we shall see, is not an identifiable individual. It may indeed well be that no individual entity can be conceived which would answer the requirements of the adequate picture stated above.

It is not at all easy to realize this lack of individuality and to find words for it. A symptom is that the probability interpretation, unless it is expressed in the most highly technical language of mathematics, seems to be vague as to whether the wave gives information about one particle or about an ensemble of particles. It is not always quite clear whether it indicates the probability of finding “the” particle or of finding “a” particle, or indicates the likely or average number of particles in, say, a given small volume. Moreover, the most popular view on probability tends to obliterate these differences. It is true that exact mathematical tools are available to distinguish between them. A point of general interest is involved, which I will explain. A method of dealing with the problem of many particles was indicated in 1926 by the present writer. The method uses waves in many-dimensional space, in a manifold of $3N$ dimensions, N being the number of particles. Deeper insight led to its improvement. The step leading to this improvement is of momentous significance. The many-dimensional treatment has been superseded by so-called second quantization, which is mathematically equivalent to uniting into one three-dimen-

sional formulation the cases $N=0, 1, 2, 3 \dots$ (to infinity) of the many-dimensional treatment. This highly ingenious device includes the so-called new statistics, with which we shall have to deal below in much simpler terms. It is the only precise formulation of the views now held, and the one that is always used. What is so very significant in our present context is that one cannot avoid leaving indeterminate the number of the particles dealt with. It is thus obvious that they are not individuals.

7. THE NOTION OF A PIECE OF MATTER

I wish to set forth a view on matter and the material universe, to which Ernst Mach [1],² Bertrand Russell [2], and others were led by a careful analysis of concepts. It differs from the popular view. We are, however, not concerned with the psychological origin of the concept of matter but with its epistemological analysis. The attitude is so simple that it can hardly claim complete novelty; some pre-Socratics, including the materialist Democritus [3], were nearer to it than were the great men who resuscitated science and molded it during the seventeenth to nineteenth centuries.

According to this view, a piece of matter is the name we give to a continuous string of events that succeed each other in time, immediately successive ones being as a rule closely similar. The single event is an inextricable complex of sensates, of associated memory images, and of expectations associated with the former two. The sensates prevail in the case of an unknown object, say a distant white patch on the road, which might be a stone, snow, salt, a cat or a dog, a white shirt or blouse, a handkerchief. Even so, within the ensuing string of events we usually know from general experience how to discount the changes caused by motions of our own body, in particular of our direction of sight. As soon as the nature of the object is recognized, images and expectations begin to prevail. The latter concern sensations as hard, soft, heavy, flexible, rough, smooth, cold, salty, etc., associated with the image of touching and handling; they also concern spontaneous movements or noises such as barking, mewing, shouting, etc. It should be noted that I am not speaking of our thoughts or considerations about the object, but of what forms part and parcel of our perception of it—of what it is to us. However, the limit is not sharp. As our familiarity with a piece of matter grows, and in particular as we approach its scientific aspect, the range of expectations in regard to it widens, eventually to include all the information science has ascertained, e. g., melting point, solubility, electric conductivity, density, chemical and crystalline structure, and so on. At the same time, the momentary sensational core recedes in relevance the more

² Numbers in brackets refer to authorities cited at the end of this article;

the object becomes familiar to us, whether by scientific knowledge or by everyday use.

8. INDIVIDUALITY OR "SAMENESS"

After a certain wealth of association has come to outshine the core of sensates, the latter is no longer needed to keep the complex together. It persists even when the contact of our senses with the object temporarily ceases. And more than that: the complex is latently conserved even when the whole string is interrupted by our turning away from the object to others and forgetting all about it. Indeed, this is not exceptional, but a rule which—since we sometimes sleep—has no exception. But we have adopted the useful device of filling these gaps. We supplement the missing parts of the strings relating to pieces of matter in our nearer and farther surroundings, to cover the periods when we neither watch them nor think of them. When a familiar object re-enters our ken, it is usually recognized as a continuation of previous appearances, as being the same thing. The relative permanence of individual pieces of matter is the most momentous feature of both everyday life and scientific experience. If a familiar article, say an earthenware jug, disappears from your room, you are quite sure somebody must have taken it away. If after a time it reappears, you may doubt whether it really is the same one—breakable objects in such circumstances are often not. You may not be able to decide the issue, but you will have no doubt that the doubtful sameness has an indisputable meaning—that there is an unambiguous answer to your query. So firm is our belief in the continuity of the unobserved parts of the strings!

No doubt the notion of individuality of pieces of matter dates from time immemorial. I suppose animals must have it in some way, and a dog, when seeking for his ball that has been hidden, displays it very plainly. Science has taken it over as a matter of course. It has refined it so as safely to embrace all cases of apparent disappearance of matter. The idea that a log which burns away first turns into fire, then into ashes and smoke, is not alien to the primitive mind. Science has substantiated it; though the appearance in bulk may change, the ultimate constituents of the matter do not. This was (in spite of his occasional skepticism mentioned above) the teaching of Democritus. Neither he nor Dalton doubted that an atom which was originally present in the block of wood is afterward either in the ashes or in the smoke.

9. THE BEARING ON ATOMISM

In the new turn of atomism that began with the papers of Heisenberg and of de Broglie in 1925 such an attitude has to be abandoned. This is the most startling revelation emerging from the ensuing de-

velopment, and the feature which in the long run is bound to have the most important consequences. If we wish to retain atomism we are forced by observed facts to deny the ultimate constituents of matter the character of identifiable individuals. Until recently, atomists of all ages, for all I know, had transferred that characteristic from visible and palpable pieces of matter to the atoms, which they could not see or touch or observe singly. Now we do observe single particles; we see their tracks in the cloud chamber and in photographic emulsions; we register the practically simultaneous discharges caused by a single swift particle in two or three Geiger counters placed at several yards' distance from each other. Yet we must deny the particle the dignity of being an absolutely identifiable individual. Formerly, if a physicist were asked what stuff the atoms themselves were made of, he might smile and shirk the answer. If the inquirer insisted on the question whether he might imagine them as small unchangeable bits of ordinary matter, he would get the smiling reply that there was no point in doing so but that it would do no harm. The formerly meaningless question has now gained significance. The answer is definitely in the negative. An atom lacks the most primitive property we associate with a piece of matter in ordinary life. Some philosophers of the past, if the case could be put to them, would say that the modern atom consists of no stuff at all but is pure shape.

10. THE MEANING OF THE NEW STATISTICS

We must at last proceed to give the reasons for this change of attitude in a more comprehensible form than at the end of section 6. It rests on the so-called new statistics. There are two of them. One is the Bose-Einstein statistics, whose novelty and relevance were first stressed by Einstein. The other is the Fermi-Dirac statistics, of which the most pregnant expression is Pauli's exclusion principle. I shall try to explain the new statistics, and its relation to the old classical or Boltzmann statistics, to those who have never heard about such things and perhaps may be puzzled by what "statistics" means in this context. I shall use an instance from everyday life. It may seem childishly simple, particularly because we have to choose small numbers—actually 2 and 3—in order to make the arithmetic surveyable. Apart from this, the illustration is completely adequate and covers the actual situation.

Three schoolboys, Tom, Dick, and Harry, deserve a reward. The teacher has two rewards to distribute among them. Before doing so, he wishes to realize for himself how many different distributions are at all possible. This is the only question we investigate (we are not interested in his eventual decision). It is a statistical question: to count the number of different distributions. The point is that the

answer depends on the nature of the rewards. Three different kinds of reward will illustrate the three kinds of statistics.

(a) The two rewards are two memorial coins with portraits of Newton and Shakespeare respectively. The teacher may give Newton either to Tom or to Dick or to Harry, and Shakespeare either to Tom or to Dick or to Harry. Thus there are 3 times 3, that is 9, different distributions (classical statistics).

(b) The two rewards are two shilling-pieces (which, for our purpose, we must regard as indivisible quantities). They can be given to two different boys, the third going without. In addition to these three possibilities there are three more: either Tom or Dick or Harry receives 2 shillings. Thus there are six different distributions (Bose-Einstein statistics).

(c) The two rewards are two vacancies in the football team that is to play for the school. In this case two boys can join the team, and one of the three is left out. Thus there are three different distributions (Fermi-Dirac statistics).

Let me mention right away: the *rewards* represent the particles, two of the same kind in every case; the boys represent states the particle can assume. Thus, "Newton is given to Dick" means: the particle Newton takes on the state Dick.

Notice that the counting is natural, logical, and indisputable in every case. It is uniquely determined by the nature of the object—memorial coins, shillings, memberships. They are of different categories. Memorial coins are individuals distinguished from one another. Shillings, for all intents and purposes, are not, but they are still capable of being owned in the plural. It makes a difference whether you have 1 shilling, or 2 or 3. There is no point in two boys exchanging their shillings. It does change the situation, however, if one boy gives up his shilling to another. With memberships, neither has a meaning. You can either belong to a team or not. You cannot belong to it twice over.

Experimental evidence proves that statistical counts referring to elementary particles must never follow the pattern (a), but must follow either (b) or (c). Some hold that for all genuinely elementary particles (c) is competent. Such particles, electrons for instance, correspond to membership in a club; I mean to the abstract notion of membership, not to the members. Any person eligible to membership in that club represents a well-defined state an electron can take on. If the person is a member, that means there is an electron in that particular state. According to Pauli's exclusion principle, there can never be more than one electron in a particular state. Our simile renders this by declaring double membership meaningless—as in most clubs it would be. In the course of time the list of members changes,

and membership is now attached to other persons: the electrons have gone over into other states. Whether you can, in a loose way, speak of a certain membership going over from Dick to Tom, thence from Tom to Harry, etc., depends on the circumstances. They may suggest this view, or they may not, but never in an absolute fashion. In this our simile is perfect, for it is the same with an electron. Moreover, it is quite appropriate to consider the number of members as fluctuating. Indeed, electrons too are created and annihilated.

The example may seem odd and inverted. One might think, "Why cannot the people be the electrons and various clubs their states? That would be so much more natural." The physicist regrets, but he cannot oblige. And this is just the salient point: the actual statistical behavior of electrons cannot be illustrated by any simile that represents them by identifiable things. That is why it follows from their actual statistical behavior that they are not identifiable things.

The (*b*), illustrating Einstein-Bose statistics, is competent for light quanta (photons), *inter alia*. It hardly needs discussion. It does not strike us as so strange for the very reason that it includes light, i. e., electromagnetic energy; and energy, in prequantum times, had always been thought of in very much the way our simile represents it, *viz*, as having quantity, but no individuality.

11. RESTRICTED NOTION OF IDENTITY

The most delicate question is that of the states of, say, an electron. They are, of course, to be defined not classically, but in the light of the uncertainty relation. The rigorous treatment referred to at the end of section 6 is not really based on the notion of "state of one electron" but on that of "state of the assembly of electrons." The whole list of members of the club, as it were, has to be envisaged together—or rather several membership lists, corresponding to the several kinds of particles that go to compose the physical system under consideration. I mention this, not to go into details about it, but because, taken rigorously, the club simile has two flaws. First, the possible states of an electron (which we had assimilated to the persons eligible for membership) are not absolutely defined; they depend on the arrangement of the—actual or imagined—experiment. Given this arrangement, the states are well-defined individuals, which the electrons are not. They also form—and this is the second flaw of the simile—a well-ordered manifold. That is, there is a meaning in speaking of neighboring states as against such as are more remote from each other. Moreover, I believe it is true to say that this order can be conceived in such a fashion that, as a rule, whenever one occupied state ceases to be occupied, a neighboring state becomes occupied.

This explains that, in favorable circumstances, long strings of successively occupied states may be produced, similar to those contemplated in sections 7 and 8. Such a string gives the impression of an identifiable individual, just as in the case of any object in our daily surrounding. It is in this way that we must look upon the tracks in the cloud chamber or in a photographic emulsion, and on the (practically) simultaneous discharges of Geiger counters set in a line, which discharges we say are caused by the same particle passing one counter after another. In such cases it would be extremely inconvenient to discard this terminology. There is, indeed, no reason to ban it, provided we are aware that, on sober experimental grounds, the sameness of a particle is not an absolute concept. It has only a restricted significance and breaks down completely in some cases.

In what circumstances this restricted sameness will manifest itself is fairly obvious: namely, when only few states are occupied in the region of the state-manifold with which we are concerned, or, in other words, when the occupied states are not too crowded in that region, or when occupation is a rare event—the terms “few,” “crowded,” and “rare” all referring to the state-manifold. Otherwise, the strings intermingle inextricably and reveal the true situation. In the last section we shall formulate the quantitative condition for the prevailing of restricted individuality. Now we ask what happens when it is obliterated.

12. CROWDEDNESS AND WAVE ASPECT

One gains the impression that according as the individuality of the particles is wiped out by crowding, the particle aspect becomes altogether less and less expedient and has to be replaced by the wave aspect. For instance, in the electronic shell of an atom or molecule the crowding is extreme, almost all the states within a certain region being occupied by electrons. The same holds for the so-called free electrons inside a metal. Indeed, in both cases the particle aspect becomes entirely incompetent. On the other hand, in an ordinary gas the molecules are extremely rare in the wide region of states over which they spread. No more than one state in 10,000 or so is occupied. And indeed, the theory of gases, based on the particle aspect, was able to attain great perfection long before the wave nature of ordinary matter was discovered. (In the last remark I have been speaking of the molecules as if they were ultimate particles; this is legitimate as far as their translatory motion is concerned.)

It is tempting to assign to the two rivals, the particle aspect and the wave aspect, full competences in the limiting cases of extreme “rarefaction” and extreme “crowding” respectively. This would separate them, as it were, with only some sort of transition required for the

intermediate region. This idea is not entirely wrong, but it is also far from correct. One may remember the interference patterns referred to in section 2 in evidence of the wave nature of the electron. They can be obtained with an arbitrarily faint bundle of cathode rays, provided the exposure is prolonged. Thus a typical wave phenomenon is produced here, irrespective of crowding. Another instance is this. A competent theoretical investigation of the collision of two particles, whether of the same or of different kind, has to take account of their wave nature. The results are duly applied to the collisions of cosmic-ray particles with atomic nuclei in the atmosphere, both being extremely rarefied in every sense of the word. But perhaps this is trivial; it only means that even an isolated particle, which gives us the illusion of transitory individuality, must yet not be likened to a classical particle. It remains subject to the uncertainty relation, of which the only tolerable image is the guiding wave group.

13. THE CONDITION FOR THE PARTICLE ASPECT

The following is the quantitative condition for strings to develop which counterfeit individuals and suggest the particle aspect: the product of the momentum p and the average distance l between neighboring particles must be fairly large compared with Planck's constant h ; thus

$$pl \gg h.$$

(The momentum p —and not the velocity—is the thing we should really have referred to when, in sections 4 and 5, we dealt with the uncertainty relation; p is simply the product of the mass and the velocity, unless the latter is comparable with that of light.)

A large l means a low density in ordinary space. What matters, however, is the density in the manifold of states—or phase space, to use the technical term. That is why the momentum p comes in. It is gratifying to remember that those very obvious strings—visible tracks in the cloud chamber or in the photographic emulsion, and simultaneous discharges of aligned counters—are all produced by particles with comparatively very large momentum.

The above relation is familiar from the theory of gases, where it expresses the condition which must be fulfilled in very good approximation in order that the old classical particle theory of gases should apply in very good approximation. This theory has to be modified according to quantum theory when the temperature is very low and at the same time the density very high, so that the product pl is no longer very large compared with h . This modification is called the theory of degenerate gases, of which the most famous application is that by A. Sommerfeld to the electrons inside a metal; we have mentioned them before as an instance of extreme crowding.

There is the following connection between our relation and the uncertainty relation. The latter allows one at any moment to distinguish a particle from its neighbors by locating it with an error considerably smaller than the average distance l . But this entails an uncertainty in p . On account of it, as the particle moves on, the uncertainty in the location grows. If one demands that it still remain well below l after the particle has covered the distance l , one arrives precisely at the above relation.

But again I must warn of a misconception which the preceding sentences might suggest, viz, that crowding only prevents us from registering the identity of a particle, and that we mistake one particle for the other. The point is that they are not individuals which could be confused or mistaken one for another. Such statements are meaningless.

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THE COMPOSITION OF OUR UNIVERSE¹

By HARRISON BROWN

*Institute for Nuclear Studies
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[With 1 plate]

One of the more difficult fundamental problems which confront science today is that of determining the chemical composition of the matter of which our universe is made. Man, bound to the surface of his planet, can see the billions of stars existing within the galaxy of which his sun is a member, and the billions of galaxies extending in all directions as far as his telescopes can penetrate; but he has only the light that the stars emit with which to work. He knows that a very large amount of matter is scattered throughout interstellar space; but he cannot sample it. He can see the other planets within his solar system; but he can study only the light that they reflect from the sun. He is even prevented by the thick solid crust under his feet from sampling the interior of his own planet.

Nevertheless he has learned a great deal about the composition of his universe from studies of what is available: Light from the stars and planets, and the matter in the meteorites he finds and in the earth at his feet. We can find significant regularities in the abundances of elements on the surface of our earth. In 1917, W. D. Harkins made the important discovery that elements of even atomic number are in general more abundant than neighboring elements of odd atomic number. But there were a number of exceptions to the rule and these were attributed to the possibility that the surface of the earth is a poor sample of cosmic matter. It was believed that if, in some manner, a sample of the earth as a whole could be obtained, the exceptions would be fewer in number. Soon thereafter many of the elements were broken down into their component isotopes and it was found that the rule could be more generally formulated: Nuclear species of odd mass number are less abundant than neighboring nuclear species of even mass number.

Other generalizations could be made on the basis of the earth's crust alone. It appeared that nuclear species of even atomic number

¹ Reprinted by permission from *Physics Today*, vol. 3, No. 4, April 1950.

whose mass numbers are integer multiples of four are more abundant than other species. It appeared further that the abundances of elements fall off rapidly with increasing atomic number.

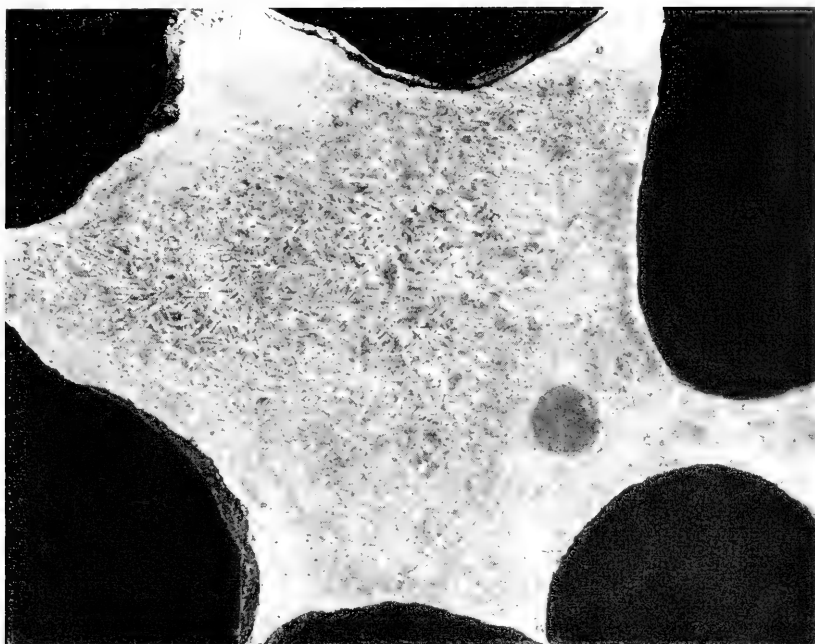
The "odd-even" and the "integer multiple of 4" abundance regularities are in themselves sufficient to permit an important conclusion. Whatever the process might have been that led to the formation of elements, it seems clear that the elements were formed in relative amounts which depended, at least in part, upon the nuclear properties of their constituent isotopes. But if one is to theorize further on the question of the origin of the elements and the relationships between abundance and nuclear composition, it is important that we obtain more quantitative data than is obtainable through a study of the earth's crust alone, which could not be expected to be a representative sample of matter in our cosmos.

THE COMPOSITION OF STARS

There are numerous dark lines or "absorption lines" in the sun's spectrum which are found to be located at the same characteristic frequencies which are observed in the emission spectra of elements studied in the laboratories of our earth. In this manner many elements which exist in the earth's crust have been identified in the sun's atmosphere. No elements have been found in the sun's atmosphere which do not exist on earth, though helium was discovered in the sun before it was isolated and identified terrestrially. The spectra of other stars are similar in nature to the sun's. Characteristic dark absorption lines are observed, leading to the conclusion that the stars are similar to our sun in general structure and composition.

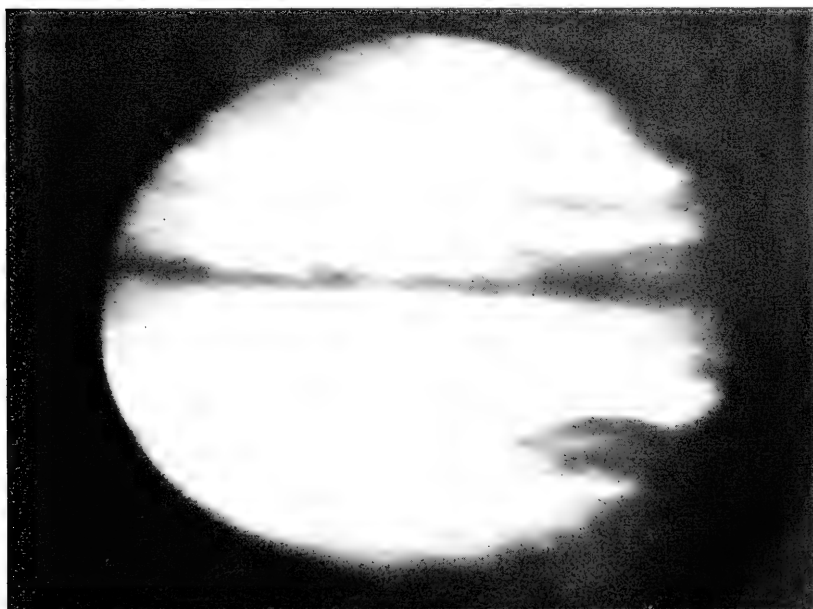
The fact that absorption lines are observed demonstrates that the continuous radiation emitted from a star's surface passes through a layer of relatively cool gas surrounding the star, the reversing layer, and so the elements in stellar atmospheres can be positively identified. But the task of converting the intensities of the lines observed in stellar spectra into relative numbers of atoms of the various species which exist in stellar atmospheres is most difficult.

Thanks to the herculean efforts of early workers in the field, such as Henry Norris Russell, C. H. Payne, and C. E. Moore, and recent developments by astrophysicists such as A. Unsöld, B. Strömgren, D. Menzel, L. Aller, and J. Greenstein, quantitative conversion of spectral intensities into relative numbers of atoms is now possible. The theory which permits the conversion of spectral line intensities into relative numbers of atoms is straightforward, but exceedingly complex, and need not be discussed here in any detail. It involves a detailed knowledge of the quantum-mechanical behavior of atomic species as functions of temperature and density, and in the presence



SECTION OF THE WILLAMETTE, OREG., METEORITE

Largest (14,175 kg.) individual iron meteorite found in the United States. It is composed almost entirely of metallic iron and nickel, two of the most abundant of the easily condensable elements (Class I).



JUPITER, THE LARGEST PLANET

It is composed almost entirely of hydrogen and helium, the most abundant elements in the universe. (Courtesy Yerkes Observatory and Hayden Planetarium.)

of many constituents. The complexity of the treatment is such that even in the most favorable cases the relative numbers of atoms of two elements cannot be determined with a precision which is better than a factor of two. Nevertheless, although the precision is not so great as might be desired, the results possess considerable significance.

Unsöld recently determined the relative abundance of elements in the sun's atmosphere as 560 atoms of hydrogen for each atom of oxygen, and 0.37 atom of carbon, 0.037 atom of silicon, 0.76 atom of nitrogen, 0.0035 atom of sodium, and 0.062 atom of magnesium for each atom of oxygen, and so on down to 0.000021 atom of vanadium for each atom of oxygen. The significance of these abundances will be apparent later on.

Whether the composition of a star's atmosphere is representative of the composition of the interior can only be answered directly. Numerous arguments have been presented to favor the conclusion that they are the same—and that they are different. In general, the arguments which favor fairly complete mixing of the elements within the sun appear to be somewhat stronger than the others, particularly with respect to elements heavier than oxygen. This is so in spite of the fact that small traces of lithium and boron, which have been detected in the sun's atmosphere, could not possibly exist for an appreciable length of time at the temperatures of the sun's interior. The sun probably sweeps up small traces of these observed elements. Secondly, the amounts of lithium and boron observed are so minute, and the region in which they could be consumed is so relatively small, that the amounts observed need not be incompatible with a relaxation time for mixing adequate to result in fair homogeneity. Additional evidence favoring good mixing will be presented when we compare and find similarities in the composition of the sun with that of other material in our solar system.

A method independent of observed spectral intensities exists for the determination of the abundances of hydrogen and helium relative to other elements in stars. The method depends first upon the general theory of stellar structure, a fundamental result of which is that for a given mass the radius and luminosity of a star will depend strongly upon the mean molecular weight of the matter of which the star is composed. At the temperatures which exist in stellar interiors atoms are completely ionized, so the mean molecular weight of a given element will be its ordinary molecular weight divided by the total number of particles produced by the ionization (electrons plus nucleus). The molecular weights of most completely ionized elements lie very close to 2 because of the fact that in general the mass numbers of nuclear species are nearly double their atomic numbers. Thus, the mean molecular weight of completely ionized iron will be

56/(26+1) or 2.1. The mean molecular weight of completely ionized oxygen will be 16/(8+1) or 1.8. However, the molecular weights of completely ionized hydrogen and helium will be only 0.5 and 1.3 respectively. Consequently, while the equilibrium within a star will not be very sensitive to the relative proportions of the heavier elements present, it will be very sensitive to the amounts of hydrogen and helium.

Thus, if we know the mass, the radius, and the luminosity of a star, we can determine its mean molecular weight and, as a result, the approximate hydrogen content of the star. In order to determine the hydrogen and helium contents more precisely, particularly relative to the next most abundant elements (carbon, nitrogen, and oxygen), use can be made of our knowledge concerning the mechanism of energy production in the main-sequence stars. In 1939, Bethe demonstrated that the mechanism of energy production in the sun, and probably in all main-sequence stars, is a cycle of nuclear reactions involving carbon, nitrogen, and oxygen as intermediates, and resulting in the net conversion of hydrogen into helium. The mathematical relationships involved in the carbon cycle can be coupled with the general relationships which describe the equilibria within stellar interiors, and a unique solution for the relative proportions of hydrogen and helium present in a given star may be obtained.

Recently Greenstein recomputed the abundances of hydrogen and helium relative to other elements (primarily carbon, nitrogen, and oxygen). His results indicate that for every atom of heavier elements present in the sun, there are approximately 100 atoms of helium and 1,000 atoms of hydrogen. Thus it appears that in our region of space, hydrogen and helium together account for more than 99.8 percent of the matter present! Relative to these elements, the elements that we encounter in such high abundance on the surface of the earth exist in stars in amounts that are quite insignificant.

How does this reasoning concerning the hydrogen and helium content of stars, and their abundances relative to other elements, apply to individual stars? Do stars differ appreciably one from the other in composition? We know that stars differ considerably one from the other in their energy release per unit weight of the star, so they must be consuming hydrogen and producing helium at rates which differ widely. As a result one would expect that the hydrogen and helium contents of stars would vary considerably. Indeed, we find collapsed stars known as white dwarfs where the hydrogen contents appear to have been virtually exhausted. Similarly, one would expect to find variations within main-sequence stars of the abundances of carbon, nitrogen, and oxygen. The ratios of these elements will be

fixed by their relative cross sections for proton capture, which will depend in turn upon the temperature condition within the stars.

Thus one would expect to find major differences in the composition of stars with respect to all elements which can undergo thermonuclear reactions at the temperatures which exist in stellar interiors. But there are limitations to the temperatures which exist in stars, and as a result one would not expect elements heavier than oxygen to undergo thermonuclear reaction to any appreciable extent. Does this mean that stars may also differ appreciably from one another with respect to the abundances of their heavier nonreactive constituents? It is very difficult to compare the abundances of elements in stars of widely differing spectral characteristics with any great precision. However, stars of similar spectral type can be compared. Recently, Greenstein compared the abundances of several elements in a number of F-type stars which possess widely different luminosities. He found that for the ordinary stars of this type no well-established abundance difference within a factor of two exists. In other words, it appears that stars possess nearly identical compositions with respect to elements heavier than oxygen.

If this result is correct for our own galaxy, is it true of the billions of galaxies which are visible to us? Unfortunately the data are too meager to permit us to draw such a sweeping conclusion. Nevertheless, the probability of such an assumption being correct appears to be considerable.

INTERSTELLAR MATTER

It is well recognized that in certain regions of our own and other galaxies as much as 50 percent of the mass exists in the form of finely divided matter distributed throughout interstellar space. Although this matter is extremely dilute, the tremendous distances between our sun and other stars result in there being sufficient gas between some stars and the earth to produce definite absorption lines, the intensities of which can be measured. If one studies the spectrum of a distant star which has a large motion either toward or away from the sun, the absorption lines produced by the reversing layer will be shifted owing to the Doppler effect. Superimposed upon the spectrum of the star one will see undisplaced lines corresponding to the absorption lines of various elements. The locations of these stationary lines are found to be independent of the velocity of the star relative to the earth, and can only be attributed to the existence of matter between the star and the earth.

The first estimates of the relative abundances of elements in interstellar material were made by T. Dunham, Jr. (1939) and by O. Struve (1941). Recently B. Strömgren has succeeded in establishing with

fair accuracy the ratios of several elements in the interstellar gas. He finds the atomic ratio of hydrogen to sodium to be 5 to 25×10^6 . This value is considerably higher than the corresponding value for the ratio of the abundances of these elements believed to exist in the sun (about 0.7×10^6) and may indicate that the interstellar gas is deficient in higher atomic weight elements relative to stars. It is noteworthy, however, that Strömgren's value for the titanium-sodium ratio is about 3×10^{-2} , which, within experimental error, agrees with the best value for the abundance ratio of the same elements in the solar system (6×10^{-2}).

In general, it appears probable that, with the exceptions of hydrogen, helium, and lighter elements whose abundances are shifted in stars owing to thermonuclear reactions, the abundances of the elements in interstellar material lie very close to their abundances in stars.

THE EARTH AND METEORITES

It has been mentioned that the study of stellar spectra gives rise to abundance values which are in the very best cases precise only to within a factor of 2. In addition, only a few elements can be determined in stars with anything approaching this degree of accuracy. If we are to extend our knowledge concerning abundances to a wider range of elements, and with a greater degree of precision, we must examine condensed material within our solar system: planets and meteorites.

Realizing that the crust of the earth constitutes a poor specimen of gross material within our solar system, the late V. M. Goldschmidt, who perhaps more than any one man can be considered to be the father of modern geochemistry, studied the composition of meteorites. In doing so, he followed the general concept which had originated many decades previously: the average composition of these bodies which fall to the earth from space is probably equivalent to the composition of the earth as a whole. In view of the fact that meteorites, as distinct from stellar spectra, can be analyzed quite precisely, it is important to investigate the validity of Goldschmidt's hypothesis.

What are the chemical relationships between meteorites and the earth? How is the earth related chemically to the sun and planets of the solar system? If we can ascertain these relationships, we will then be in a position to utilize meteorites in an evaluation of elemental abundances.

A century ago, the scientist Boisse first suggested the possibility assumed by Goldschmidt. Since that time considerable effort has been expended by astronomers, geologists, geophysicists, and geochemists in attempts to develop or to disprove Boisse's speculation. On the whole,

information accumulated during the last 50 years has served to substantiate the thesis that meteorites belong to a single family possessing a common genesis, quite possibly a planet similar to the earth in physico-chemical characteristics.

Meteorites range in size from dust particles (which are most difficult to collect) to many tons. In general, meteorites fall into two distinct categories—irons and stones. Iron meteorites are fragments of pure metal, consisting primarily of an alloy of iron containing about 8 percent nickel and 2 percent minor constituents. Stony meteorites consist primarily of magnesium and iron silicates through which finely divided particles of metallic iron-nickel are dispersed. The average metal-phase content of stony meteorites is approximately 11 percent, but the quantity of metal may vary from nearly zero to well over 50 percent. A third and less abundant meteoritic phase, known as troilite, and composed primarily of ferrous sulfide, exists in both stony and iron meteorites, usually distributed throughout the mass, but frequently collected into pockets of substantial size.

A comparison of the abundances of elements in meteorites, the earth's crust, and the sun demonstrates that both meteorites and the earth are very deficient in those elements which are most abundant in the sun (hydrogen, helium, carbon, nitrogen, and oxygen). Meteorites, in turn, possess considerably larger proportions of iron and magnesium and smaller proportions of sodium and potassium than are observed in the earth's crust.

Meteorites are much more dense than the surface rocks of the earth. In view of the fact that the earth as a whole has a mean density nearly double that of its surface, the assumption that the earth possesses a composition equivalent to the composition of meteorites would appear to be plausible. In this event, it would be necessary to assume that considerable quantities of metallic iron, together with iron and magnesium silicates, exist below the earth's surface.

The hypothesis that the earth possesses a composition equivalent to that of meteoritic matter was fortified by the discovery of the seismic discontinuity of first order located at approximately one-half the earth's radius. It appeared reasonable to assume that this discontinuity marked the boundary of a core composed of metallic iron-nickel (similar in composition to iron meteorites). The silicate mantle surrounding the core would then possess a composition equivalent to stony meteorites.

A study of the trace constituents in meteorites demonstrates that elements are distributed between the metallic and silicate phases according to well-recognized chemical laws. Those elements which possess low affinities for oxygen (i. e., gold, palladium, platinum) exist almost entirely in the metallic phase; those elements which possess

high affinities for oxygen (i. e., sodium, potassium, strontium, barium) exist almost entirely in the silicate phase. A survey of the earth's crust demonstrates that elements of low oxygen affinity, such as the platinum metals, exist in exceedingly low concentrations when compared with neighboring elements of high oxygen affinity. If we assume that a metallic phase exists within the earth, the low abundances of these elements in the crust can be explained on the basis that they exist in considerably higher abundance in the deep-seated regions of the earth in association with metallic iron.

With these general ideas in mind Goldschmidt, together with several chemists who had become interested in the problem, determined the concentrations of many elements in iron and stony meteorites. Goldschmidt then utilized the data in 1937 to compile the first fairly complete table of relative abundances.

One difficulty associated with the compilation of such an abundance table was that of coupling meteoritic abundances to solar abundances. Goldschmidt utilized the then existent solar data and adjusted meteoritic silicon so that it would be equal to solar silicon. A second difficulty was that of combining iron meteorites with stone meteorites in proper proportions. Unfortunately iron and stone meteorites fall through the atmosphere in different ways, with the result that there is a higher probability of observing a stone fall than an iron fall. Stony meteorites tend to break into fragments while passing through the atmosphere, thus producing more spectacular displays than do iron meteorites. On the other hand, many meteorites reach the ground without actually having been seen to fall. As stony meteorites appear to the untrained eye to be rocks, many of them are never collected. Iron meteorites, being more unusual, are picked up more frequently.

Goldschmidt, in the absence of adequate information, chose a ratio of metal to silicate of 1:5; but observations of both the earth and the sun lead us to believe that perhaps it should be closer to 3:5.

An approximate figure for the ratio of metal to silicate can be obtained by calculating the weight of the earth's core relative to the earth as a whole. The core of the earth is, of course, compressed owing to the tremendous pressures in the interior; at the center, the pressure is approximately 3 million atmospheres. We do not know experimentally the compressibility of iron at such high pressures, but in recent years a number of theoretical studies have been made. Utilizing the Fermi-Thomas statistical atomic model, calculations of potential fields and charge densities in metals as a function of lattice spacing can be made. Such calculations make possible the determination of pressure-volume relationships at extremely high pressures. It has been found that the results of such a calculation made on iron are compatible with estimates of the densities within the earth's core derived from

seismic-wave studies. Knowing the location of the core boundary and the density of iron as a function of pressure, the mass of the core can be readily determined. It is found on such a basis that the ratio of the weight of the core to the weight of the mantle is approximately 0.5. If one assumes that the mantle contains an amount of metal phase equivalent to that found in stony meteorites, the weight ratio of metal to silicate for the earth as a whole would be approximately 0.6 or 0.7.

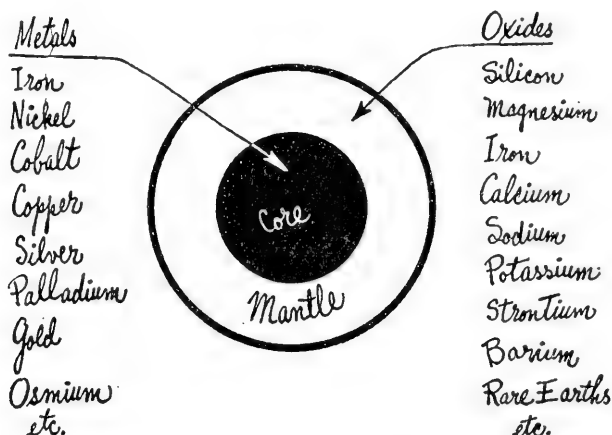


FIGURE 1.—Distribution of elements in the earth.

Utilizing the above figures for the ratio of metal to silicate, and replacing many of Goldschmidt's abundances with more recently determined values, a revised set of abundances of elements in gross meteoritic matter has been computed and has been published in the *Review of Modern Physics*, October 1949.

In spite of the errors involved (primarily in the solar data), the abundances of the elements in gross meteoritic matter correspond quite well with the abundances of these elements as found in the sun, indicating strongly that insofar as certain elements are concerned, meteorites possess essentially the same composition as the sun. All the elements in question possess relatively high boiling points, or their oxides possess high boiling points. In other words, it appears reasonable to assume that, with respect to easily condensable substances, meteorites and the sun possess nearly identical compositions. Fortunately, although these elements constitute less than one-half of 1 percent of the mass of the sun, they include no less than 71 of the stable or long-lived elements existing in nature. Thus, it appears that a study of the relative abundances of elements in meteorites can give us important abundance information which covers a wide range of elements, and which has considerable cosmic significance.

THE PLANETS

Can there be relationships between the other planets similar to the assumed composition relationship between meteorites and the earth? The planets can be readily divided into two main groups—small planets of high density (Mercury, Venus, Earth, and Mars) and large planets of low density (Jupiter, Saturn, Uranus, and Neptune). It seems clear that the smaller planets are composed almost entirely of the easily condensable substances which constitute such a small fraction of stellar material. Although the variations in density among the smaller planets are considerable, it appears that at least among three of them (Mars, Venus, and the Earth) a substantial amount of the density variation is due to increasing compression with increasing mass. The new determination of the mass of Mercury indicates that some variation in the metal to silicate ratio may exist, but this is uncertain.

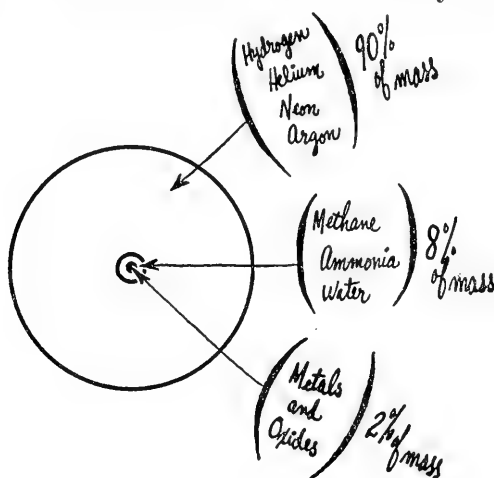


FIGURE 2.—Distribution of elements in Jupiter.

Recent developments in the theory of the origin of the solar system make it appear probable that the planets were formed by a process of condensation at low temperature from a medium possessing a composition close to that of the present sun. The terrestrial planets were formed from those substances which were least volatile. In the regions of the outer (or Jovian) planets, conditions were such that some of the lighter and more abundant materials could condense as well, thus giving rise to much larger planets of considerably lower density.

If we assume the present abundance values for the sun to be the most probable values for the abundances of the elements in the pre-planetary medium, we can assess the most likely chemical forms in which the elements would exist at reasonable temperatures. For each part by weight of easily condensable material (earth-forming elements) we would have approximately 4 parts by weight of a mixture

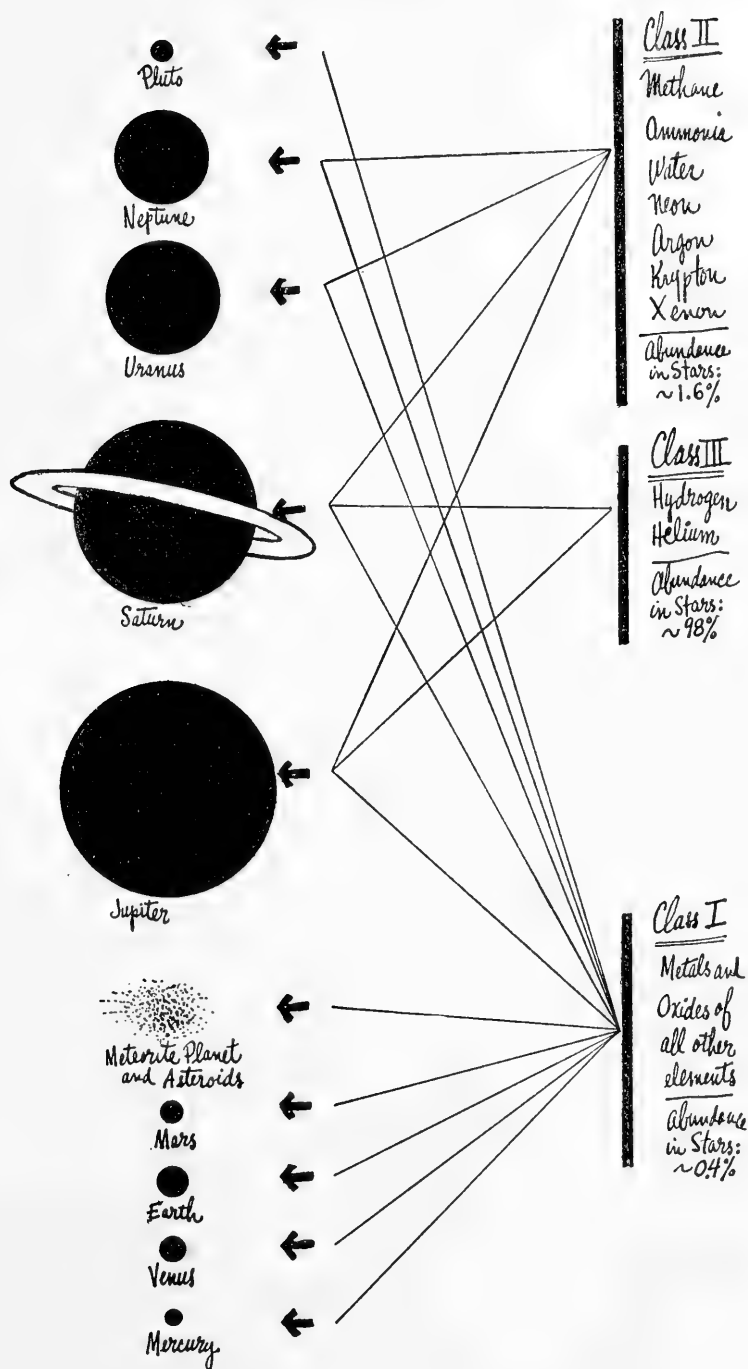


FIGURE 3.—Location of chemical species in planets.

of methane, ammonia, water, and rare gases, 56 parts by weight of helium, and 180 parts by weight of hydrogen.

If we assume the above composition, then it appears likely that Uranus and Neptune, the two planets of size intermediate between the terrestrial planets on the one hand, and Jupiter and Saturn on the other, captured substances of intermediate condensability and molecular weight. This capture process enormously increased the masses of the planets, owing to the rather high abundances of water, methane, and ammonia.

Saturn and Jupiter condensed sufficiently rapidly and grew to a size sufficiently large to permit their capturing the very abundant gases hydrogen and helium. The preponderant abundances of these elements permitted the two planets to develop into the giants of the solar system.

A careful study of the Jovian planets utilizing theoretical studies on the behavior of matter under very high pressures demonstrates that the above picture of the compositions of the planets in relation to the composition of the sun is essentially correct. In order of increasing size we have first the terrestrial planets composed of metal and rock. We next have Uranus and Neptune with earthlike cores composed of metal and rock, surrounded by very thick layers of ice, liquid ammonia, and methane, and thin atmospheres of hydrogen and helium. Following this, we have Saturn and Jupiter composed of Uranuslike cores surrounded with thick layers of hydrogen and helium. Indeed, approximately 90 percent of the mass of Jupiter appears to be composed of these gases!

Studies of planetary atmospheres by Kuiper and others substantiate the general picture. Methane, which is a very volatile substance, is detected in considerable concentration in the atmospheres of Jupiter, Saturn, Uranus, and Neptune. Ammonia has been observed in the atmosphere of Jupiter (the warmest of the four). Presumably the vapor pressure of ammonia is too low in the other three to permit its detection. Water has such a low vapor pressure at the temperatures of the Jovian planets that it cannot exist as an atmospheric constituent.

There is still much to be done if we are to have a clear picture of the composition of our cosmos. There must be increased precision in the determination of the composition of stars and interstellar matter. There must be increased precision in the determination of the composition of meteorites and the earth's crust. Theoretical studies must be continued on the relationship between stars, interstellar matter, planets, and meteorites. But already, in spite of the meager data, a pattern is unfolding that suggests strongly that our cosmos is remarkably uniform in chemical composition. It is to be hoped that by the time another decade has passed, we will know the composition reasonably accurately.

THE WRIGHT BROTHERS AS AERONAUTICAL ENGINEERS ¹

By M. P. BAKER

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[With 9 plates]

Almost by accident, a little over a year ago, I was asked to explain the working principle of some of the Wright wind-tunnel instruments and, upon encountering some difficulty, was given complete access to the library material of the late Orville Wright. Since this material included such a wealth of technical detail pertaining to the development of the first airplane and to the engineering ability of the Wright brothers, permission was sought, and granted, to reveal it in a paper for this society. For the most part, these technical details have never been published heretofore.

Wilbur Wright has said that his active interest in aeronautics dated back to the account of Lilienthal's fatal glider accident in 1896. After studying all the literature that was handily available on the subject of aeronautics, he aroused an equal interest in his brother Orville, and the two of them drew some rather positive conclusions from what they had read :

1. A fixed-wing structure was far more practical than any scheme of flapping the wings.

2. The customary method of obtaining longitudinal and lateral control merely by shifting the operator's weight on the craft was highly inadequate. They felt that such a system necessitated a degree of skill and dexterity that was impossible to attain.

3. By proportioning a wing on the basis of known lift and drag characteristics of a chosen curved surface, and by providing a manual system for longitudinal and lateral control, one should be able to build an efficient glider in which considerable flight experience could be safely accumulated.

The solution to the longitudinal control had been given previously by the horizontal "rudder" patent issued jointly to Chanute and Mouil-

¹ Paper presented at the National Aeronautic Meeting of the Society of Automotive Engineers, April 17-20, 1950. Reprinted by permission of the SAE.

lard in 1897. However, it was not until Wilbur idly twisted an open-ended cardboard container that he conceived the idea of a biplane wing structure, cross braced as a Pratt truss in the vertical plane of the two spars, and yet an assembly that could be warped easily for lateral control. The thought was promptly tested in the form of a 5-foot kite controlled by extra strings to the ground.

1900—THE FIRST YEAR'S WORK

With characteristic enthusiasm, the Wrights designed, built, and tested their first full-scale glider (pl. 1, fig. 1) in the summer of 1900. Our design information on this machine is very meager, it being based solely on the two remaining photographs and flight records. Apparently, the Wrights sought to attain pitching control by ground adjustment of a fixed front horizontal "rudder," shifting the operator's weight or using ballast or both, and making the "rudder" controllable. There is no information on the latter method other than mention of it in their writings.

Lateral control was attained by warping the wing tips, presumably by an interconnecting wire across-ship, and somehow actuated by the feet. There were no means whatever provided for directional control.

The wing panels had a 5-foot chord and 16½-foot span, giving a total area of 165 square feet. The weight of the craft was 52 pounds. The wing section had a camber ratio of 1/22, with the peak well forward.

The craft was tested in three different ways: (1) As a man-carrying kite in winds over 25 miles per hour; (2) as a simple kite controlled from the ground in light winds; (3) as a glider off the hilltop. With the craft used as a simple kite, the L/D ratio could be computed as 6.2 from the measured pull of the tow line. As a glider, the L/D measured 6.3.

Although their actual glider flight time totaled scarcely over 2 minutes for some 12 flights, the summer's experiments did permit them to draw some very valuable conclusions:

1. Their method of wing warp was quite satisfactory, and proper pitching control could be obtained by means of a movable horizontal "rudder."

2. Their lift was less than anticipated, which they reasoned might be due to using too flat a camber, air leak in the unfinished cloth wing covering, or possible error in Lilienthal's tables of lift characteristics.

3. Their drag measurements were much less than they had estimated. There seemed no explanation for this unless the Lilienthal tables were in error.

the area of the surfaces given here was 6 1/2

The area of the normal plane against which they

were balanced was 8 sq. in. or 1/3 more than

of the surfaces whose lifts were being measured.

Designation of surface	*1	*2	*3	*4	*5	*6	*7	*8	*9	*10	*11	*12	*13	*15	*16	*17
Area in sq. in.	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Lift in gms.	0	0	0	-5 1/2	-4 1/4	-3 1/2	-3	-2 3/4	-2 3/4	-3	-2 3/4	-2 1/2	-4	-4 1/4	-4	-3 3/4
Angle in degrees	0°	0	0	7 1/2	6	5 3/4	8 1/2	8	7 1/2	8	7 1/2	7	6 1/4	8 1/4	4 1/2	4
"	2 1/4	5 1/2	7 1/4	11 1/4	8 3/4	8 1/2	17 3/4	17 1/4	15 3/4	18 1/4	16 1/4	13 1/2	15	8	6 3/4	6 3/4
"	4 7/8	11 1/2	13 3/4	15	12 3/4	17 3/4	25	23 1/2	22 1/2	26 1/2	25	22 1/2	22 1/2	12 1/2	10 1/2	9 1/4
"	8	17 1/4	20 1/2	18 1/2	16	19 1/2	31 1/2	29 1/2	27 3/4	33 1/2	32	32	27 3/4	16	14 1/4	13 1/2
"	11 1/2	22 1/4	27	22 3/4	19 3/8	19	38 1/2	39	39	36	37	39	29 1/4	19 3/8	19	17 1/4
"	15	27 1/2	30 1/2	27	24	22 1/2	52	49 3/4	46 1/2	36 1/2	37	44	30 1/2	24	22 1/2	21 3/4
"	19	31 1/4	32	32 1/2	28 1/4	27 1/4	61	59 1/2	50 1/2	38	38 3/4	46 1/2	32 1/2	29 1/4	28	26
"	23 1/4	32	33	37 1/2	33	32 1/4	63 1/2	55 1/4	51	39	41 1/2	45 1/2	34 1/4	36 3/4	33	31
"	27	33 3/4	35 1/4	42	39	26 1/4	60 1/2	52	48 3/4	41	42	44	35 1/2	40 1/2	37 1/2	35 3/4
"	34 1/2	38 3/4	22 3/4	49 1/2	47	44 1/2	50 1/4	47 1/2	44	44 1/2	41 1/2	41 1/2	36	49	47 3/4	44 1/2
"	35 1/4	31 1/4	32 1/2	57 1/2	54 3/4	49 1/2	46 3/8	44	41 1/2	41	39 1/4	39 1/4	37 1/2	56	52	49 1/2
"	37 1/4	30	32 1/2	55 1/2	55 1/2	60	44	42 1/2	40 3/4	39 3/4	38 3/4	38 1/2	—	52 1/2	48	45 1/2
"	29 1/2	28	32 1/2	47 1/2	40	38 1/2	43 1/2	41	40	39	38 1/4	38	—	38	34	32 1/2
"	27	32 1/2	35	33 3/4	30 3/4	41 3/4	39 1/4	38 1/4	37	36 1/2	38 1/4	37	36 1/2	30 1/2	29 1/2	29
Dist. in. from h. m.	False Lifts in Rectangular Passages. 16															

FIGURE 1.—Typical lift measurements.

FURTHER EXPERIMENTS THROUGH 1901

Encouraged by their first year's experiments, the Wrights designed and built a larger glider (pl. 1, fig. 2) late in the spring of 1901, with the express purpose of improving the performance as a man-carrying kite so that many hours of control experience could be built up at minimum risk. To this end, the new craft had a wing spread of 22 feet, a total area of 290 square feet, and a rib section that had a camber ratio of 1/12, to conform more closely to Lilienthal's tables. The new elevator was proportionately larger and was controlled by deflecting its trailing edge. Apparently, the wing warp was controlled in the same manner as in the earlier glider.

The equivalent monoplane aspect ratio of the new machine was 2.9 as compared with 2.87 for the first year. The structure weight was

1120

① Designation. Surface.	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17
Angle of incidence: 0°	19½	16	13½	18	12¾	11	17½	15½	14¾	14½	19¾	19¾	20	
" 2½°	11¾	9	7¾	7½	5½	4	6¾	6	5½	8¼	12	11¼	16½	
" 5°	7¾	5	4	3	2	1	2¾	1¾	1	5	8¼	7	6	
" 7½°	4¾	2½	2¼	½	-¼	-1½	1	-¼	-1½	3½	4¾	4	3	
" 10°	2¾	1	¾	-1¾	-3	-3¾	0	-1¾	-3¼	3	3	2	1½	
" 12½°	1¾	-½	-½	-4½	-5	-5	-½	-2½	-4¾	2	1¾	0	-¼	
" 15°	0	-1½	-1½	-6	-5	-5	-1½	-2½	-4¾	1¼	0	-1½	-2	
" 17½°	-¾	-1½	-1½	-6½	-4	-4	-1½	-3	-3½	¾	-1½	-2¾	-3	
" 20°	-2	-2½	-2	-5	-3¾	-3	-2¼	-2¾	-2¼	-½	-3½	4	-4½	
" 24°	-3½	-2½	-2½	-3¾	-2	-1¾	-3	-1½	-1½	-1¾	-5	5¾	-4¾	
" 30°	-3¾	-3	-2	-2	-1½	-1¼	-2	-1½	-1	-2½	-5½	-4	-2¾	
" 45°	-1¾	-1½	-1½	-1¾	-1¼	-1	-1¾	-1	-¾	-1½	-2½	-1¾	-1½	

28

Tangentials. [Over]

FIGURE 2.—Typical drag measurements.

108 pounds; thus, the new wing loading was 0.37 pound per square foot, against 0.32 pound per square foot for the earlier machine.

From the first trials of the machine, as a glider, it was soon apparent that the new wing curve induced pitching moments that were beyond the capacity of the front elevator to balance. They were able to avoid disastrous stalls and dives only by shifting their body weight. By removing the upper wing and restraining it in a high wind, they were able to lay the trouble to center-of-pressure travel and to recapture the more stable performance of the first year's craft by trussing down the ribs to a lesser camber.

They made many successful glides with the machine as altered, but upon trying it as a kite, as originally intended, they found that the lift was less than one-third of their predictions. To test whether this was caused by porosity of the wing covering, two small test surfaces were measured in natural wind with negligible difference.

Aside from the valuable flight experience gained with this machine, the summer's observation taught them the following:

1. Published lift characteristics for curved surfaces were definitely in error.

2. Over-all efficiency depended upon L/D rather than lift alone.

3. The relative position of the upper and lower wings decreased the theoretical total lift of the individual surfaces, that is, they noticed biplane effect.

4. The customary method of expressing the air force acting on a wing in terms of a pressure normal to the chord line had led them into a misconception of the net lift and drag components. Although they did not express their understanding of this in these words, there seems little doubt that this was the primary motive in designing the test instruments that will be described later.

In a paper read September 18, 1901, before the Western Society of Engineers, primarily a society of civil engineers, Wilbur Wright mentioned a series of experiments that they had begun for measuring the magnitude and direction of the forces acting on various types of curved surfaces. We know now that these experiments began upon their return from North Carolina and followed a rather interesting development pattern.

The first attempt at measuring the characteristics of a surface in model size is shown in plate 2, figure 1. Here we see a bicycle wheel mounted horizontally on tubes extending forward from the handle-bars of an ordinary bicycle (of their own manufacture). At one point on the wheel was mounted a flat plate. Some 120° removed from this point was mounted the model surface. The test surface was adjusted in angle of attack until its lift would just balance the flat-plate resistance riding normal to the wind when the bicycle was pedaled forward.

In a letter to Octave Chanute, October 6, 1901, Wilbur told about using this device and how they were able to check the ratio of the lift of a surface at any angle of attack versus its flat-plate resistance. Also, he noted that the Smeaton formula for flat-plate resistance, $P=0.005AV^2$, as used by the United States Weather Bureau, was evidently in error, and suggested that a constant of 0.0033 would be nearer the truth.

In this same letter, Wilbur stated that the bicycle test was very poor for measuring surfaces at small angles and went on to describe their

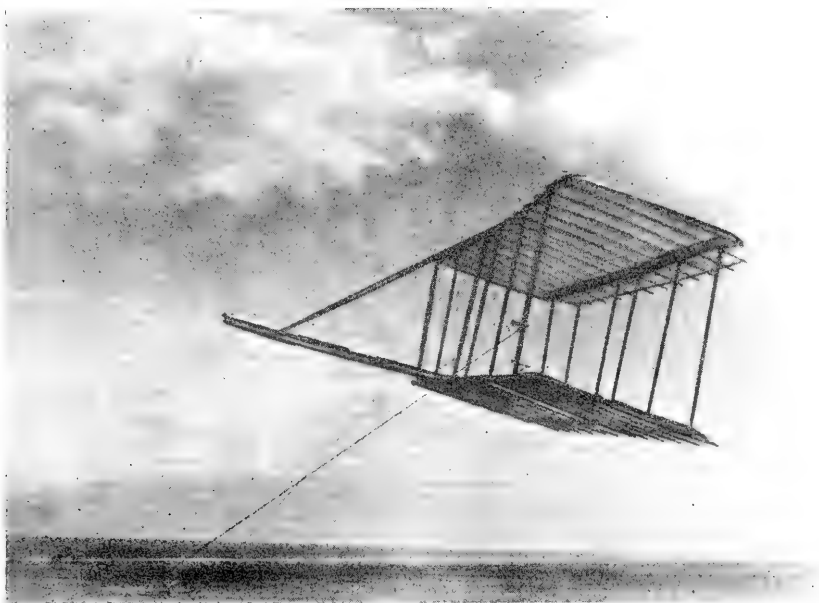
next device, shown in plate 2, figure 2. Note that two surfaces are attached to a trailing arm in wind-vane fashion and each can be adjusted until their opposing lifts balance. Later correspondence brings out the fact that this was their first attempt at using a wind tunnel and that it was actually made by knocking the ends out of a box used in those days for shipping laundry starch. An air blast was supplied from the opposite end by a screw fan turning 4,000 revolutions per minute. No doubt this was driven from their machine-shop lineshafting, which, incidentally, was driven in turn by a 2-horsepower gasoline engine of their own design.

With this device they experimented with various aspect ratios and curvatures. One particular observation that was recorded was the balancing of a 1- by 3-inch curved surface at $43\frac{1}{4}^{\circ}$ against a flat plane of the same area at $91\frac{1}{2}^{\circ}$, whereas their reference tables indicated they should have balanced at angles of $43\frac{1}{4}^{\circ}$ and 24° respectively. The correspondence files include a letter to Chanute, wherein Wilbur pointed out a number of these discrepancies. Chanute very promptly answered back that they were comparing results taken from moving wind measurements against measurements that had been made in still air. It was rather amusing to note Wilbur's reply that this should make no difference, although he did temper his brusqueness by explaining how easy it would have been for the particular investigator to have made mistakes by the method he was using.

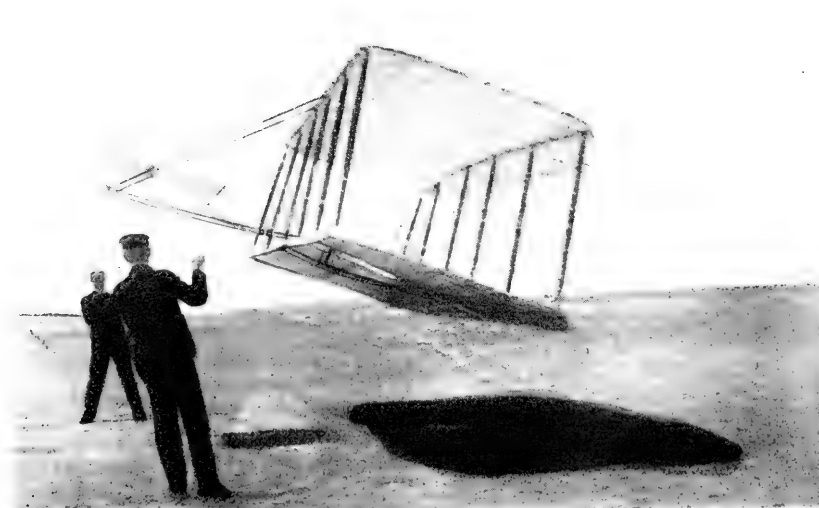
Compared with the first device, this method was far more accurate and served to make many more comparisons in a short time; however, it still did not provide the means of making direct measurements and was soon abandoned.

The third and final type of measuring instrument was evidently built and put into operation sometime between October 16 and November 14, 1901. During that time they built a tunnel like that shown in plate 3, figure 1. This is as near to an exact replica as it is possible to build from the available information. The lift instrument (see pl. 3, fig. 2), which was placed at the downwind end, is an exact copy of the original, which is now on display at the Franklin Institute in Philadelphia.

Perhaps the most unique feature of this instrument is the way in which the lift of a model surface is made to balance the flat-plate resistance of four small fingers on the lower bar. The shackle arms which support the upper crossbeam are snug on the vertical pins and are adjusted so that they trail straight with the wind stream. Since the resistance on lower beam must ride at some angle to the side in order to balance the lift of the test surface, it is obvious that the sine of the angle observed on the scale is the true lift coefficient. Angle of attack was recorded by separate protractor. A two-bladed 24-



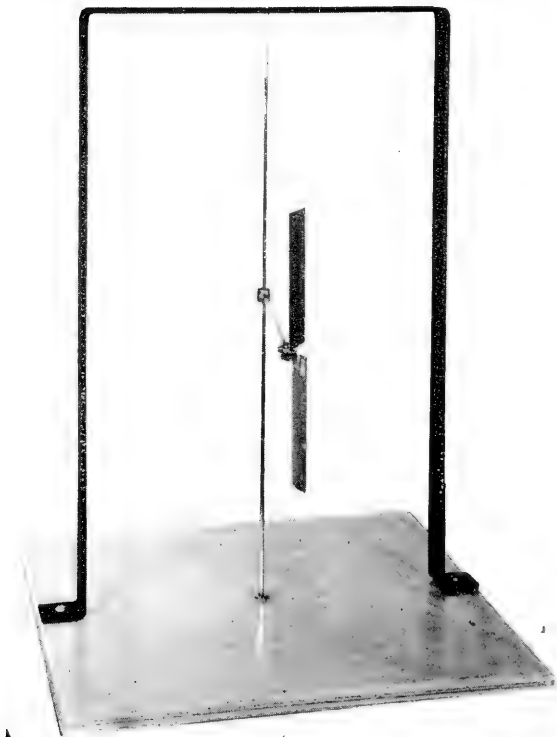
1. THE 1900 GLIDER



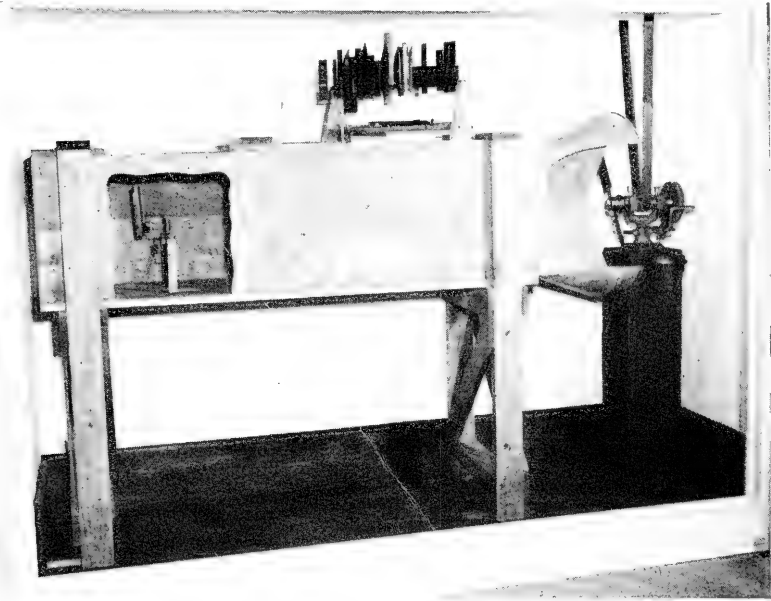
2. THE 1901 GLIDER



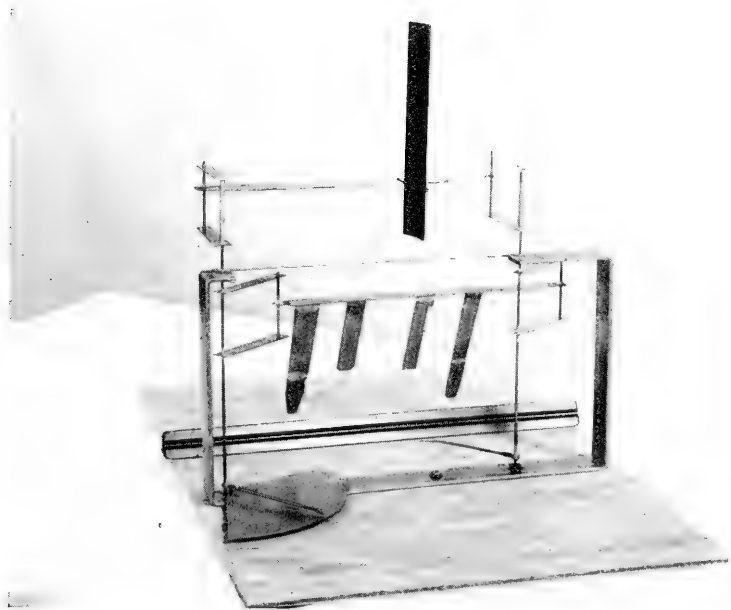
1. LIFT INSTRUMENT MOUNTED ON BICYCLE



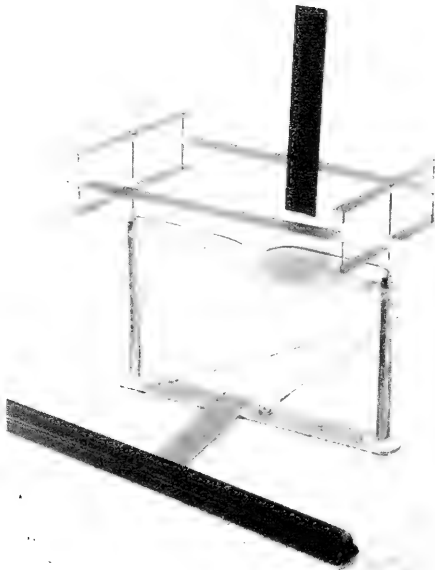
2. VANE-TYPE COMPARATOR



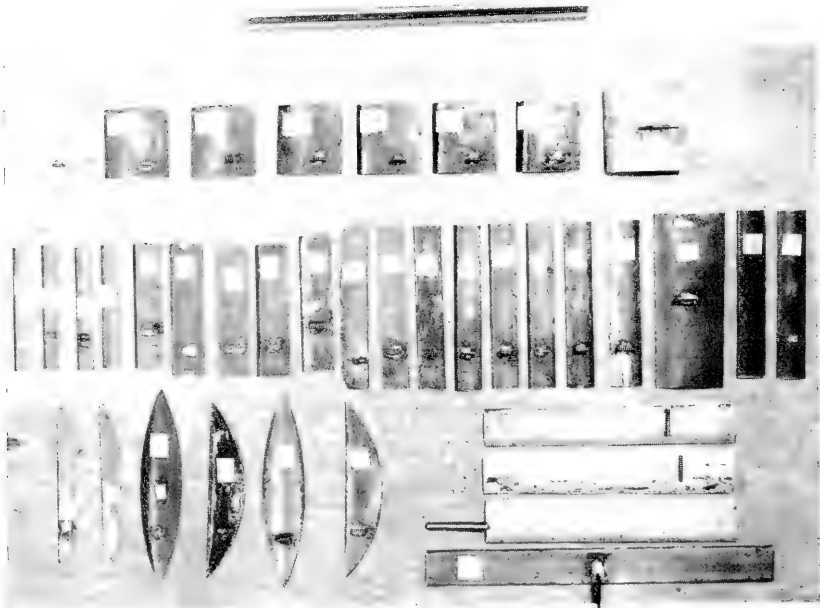
1. REPLICA OF 1902 WIND TUNNEL



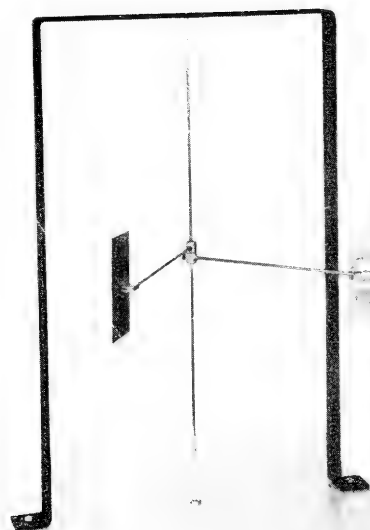
2. LIFT-MEASURING INSTRUMENT



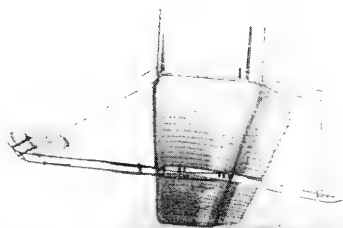
1. INSTRUMENT FOR MEASURING DRAG



2. TEST SPECIMENS USED IN WIND TUNNEL



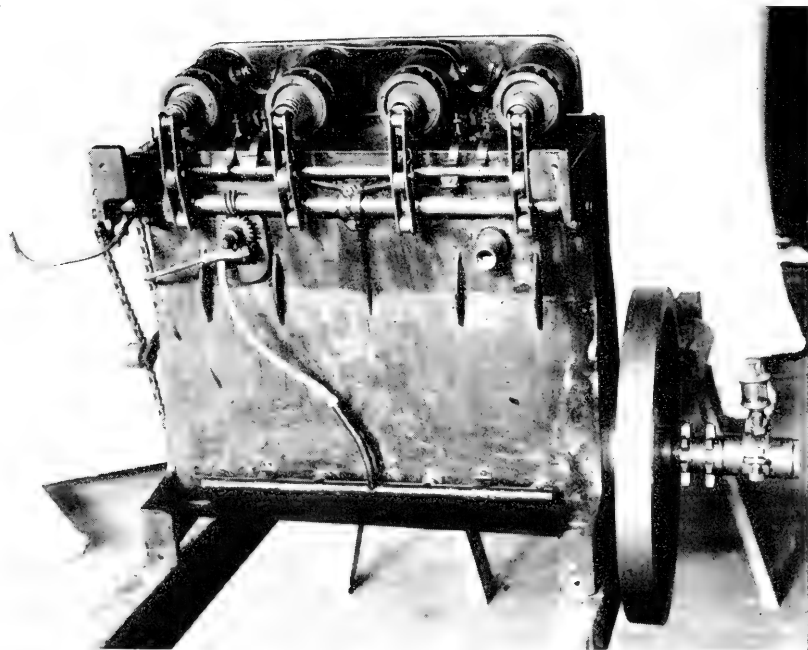
1. RECHECK VANE



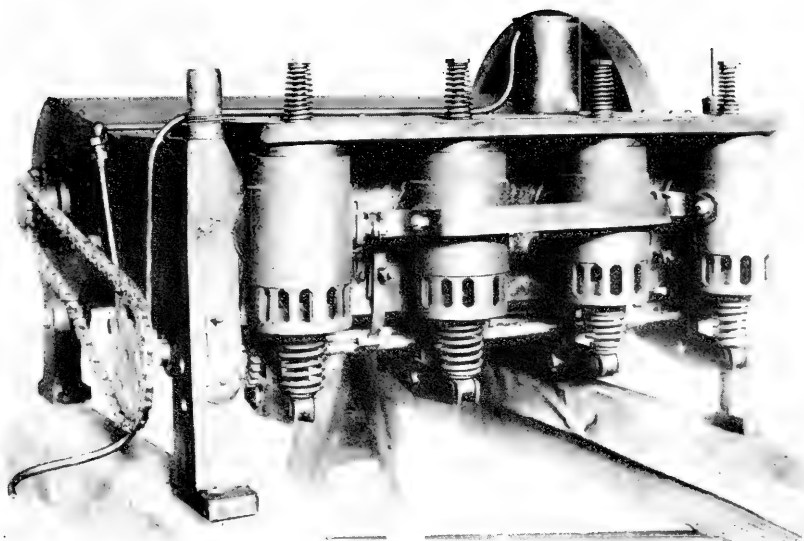
2. 1902 GLIDER



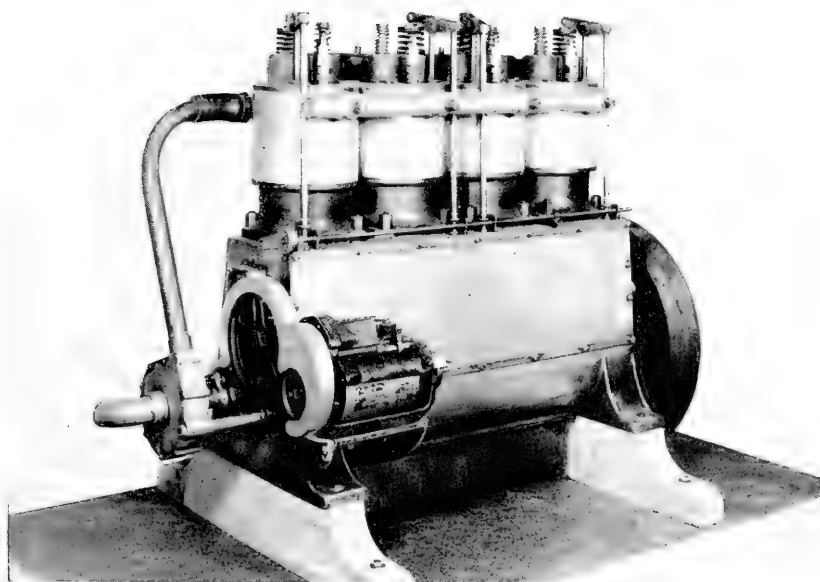
1. A THREE-VIEW OF THE 1902 GLIDER MADE BY WRIGHT FIELD ENGINEERS UNDER THE DIRECTION OF ORVILLE WRIGHT



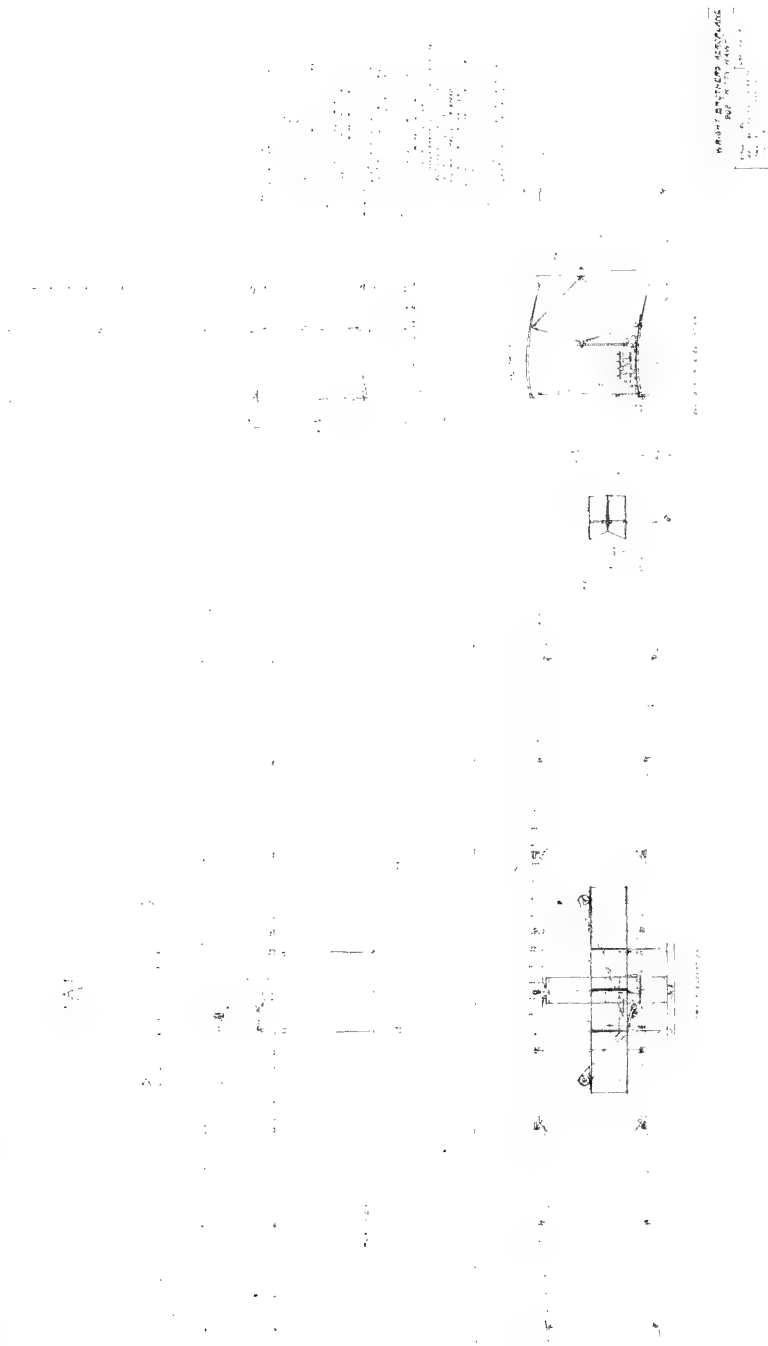
2. BOTTOM VIEW OF "KITTY HAWK" ENGINE



1. "KITTY HAWK" ENGINE IN UPRIGHT POSITION



2. THE 1908 VERTICLE ENGINE



A RECENT THREE-VIEW MADE OF THE 1903 AIRPLANE

inch-diameter propeller fan mounted on the shaft of their shop bench grinder driven at 3,000 revolutions per minute provided a wind velocity of about 27 miles per hour. The precautions taken to insure a straight flow included the quadrant shield, a grid frame, and small areas of wire mesh at strategic points on the grid.

The files indicate that the Wrights had a method of altering this instrument to measure drag, but as it was not too satisfactory they soon developed a separate instrument for that purpose. Plate 4, figure 1, shows that the drag instrument was just as ingenious as the other, but with the difference that here they measured D/L rather than drag alone. Note that the lift acts in the direction of the shackle arms, and, therefore, the tangent of the angle indicated by the dial pointer is really the prevailing D/L ratio. The angle of attack could be adjusted readily by turning the whole assembly about its mounting screw. The product of the lift coefficient and the D/L ratio for any model and setting gave the drag coefficient.

Each of these instruments is surprisingly sensitive when acted upon by even a very light breeze. By closing all doors and windows of their shop and allowing no one to move about in the room, they obtained data which requires very little fairing to plot as smooth curves.

Plate 4, figure 2, is a photograph of their remaining test models, and text figures 1 and 2 are reproductions of two pages from their "little black notebook" giving some of their typical data.

At the beginning of this test work, the Wrights believed that lift was proportional to the angle of attack, and we can well imagine their surprise at suddenly observing one day that the lift for one particular surface was the same at 30° as it was at 50° . Here again, we note their ingenuity in mounting two of this type surface on vane arms at 80° spread, checking to see if the surfaces balanced in the tunnel at 30° and 50° . This device is shown in plate 5, figure 1.

At the completion of their test program, the Wright brothers not only had an imposing collection of measured data but were also able to draw the following conclusions:

1. Increasing aspect ratio does not increase maximum lift but does lower the attack angle at which maximum lift occurs.
2. Curvature gives greater lift to a surface and a steadier rate of increase.
3. The camber ratio of a curved surface has a more marked effect on drag.
4. By having the maximum-camber point forward, lift is increased at the smaller angles.

They observed the inefficiency of biplane effect. Also they observed the effects of the taper and cut-outs in the wing plan form. They noted the stall point, although they didn't define it as such.

The accuracy of these conclusions is truly amazing when we consider the size of their models and the short time they had to accumulate the information. We must not overlook the fact that this was quite contradictory to and beyond the work of all other investigators who were "better" equipped. The importance of this phase of their work is best expressed in Wilbur's own words of 1908, "As soon as our condition is such that constant attention to our business is not required, we expect to prepare for publication the results of our laboratory experiments, which alone made an early solution of the flying problem possible." Unfortunately, this ambition was never fulfilled. This phase of their work was completed in February of 1902.

ADVANCED GLIDER WORK IN 1902

Fortified with considerable flight experience and much design data in which they had complete confidence, the Wrights returned to North Carolina in the late summer of 1902 and constructed their third glider. (See pl. 5, fig. 2, and pl. 6, fig. 1.)

From the photograph it is apparent that this machine incorporated all the refinements found necessary in the earlier models and, in addition, was fitted with a pair of fixed vertical fins for directional stability.

The new wing section had a camber ratio of $1/25$, with the high point well forward. The total wing area was 305 square feet, the front elevator had an area of 15 square feet, and the total area of the vertical tail fins was $11\frac{2}{3}$ square feet. The wing span was 32 feet 1 inch with a chord of 60 inches or an equivalent monoplane aspect ratio of 3.91. The gross weight without operator was 116.5 pounds. The elevator was controlled by a window-sash cord over pulleys (by the hand), and wing warp was operated by wires running from a cradle in which the operator's hips rested.

The lift-drag ratio of the new machine was soon established in a measured glide as 8.77. Ratio of their best previous machine had been slightly less than 6. The new elevator was very efficient, requiring only 3° either side to maintain complete pitch control. By flying the upper wing alone as a kite and by measuring all their glides carefully, they substantiated the results of their wind-tunnel experiments.

In addition to the valuable flight experience they accumulated on this machine in almost 1,000 glides during two months, they learned how to overcome a rather vicious tendency to stall in the turns by replacing the fixed vertical fins with a single movable rudder controlled by interconnection with wing warping. They later revealed this idea in their patent No. 821393 granted May 22, 1906.

The season's work gave them utmost confidence in their ability to add an engine and continue their work in powered flight.

POWERED FLIGHT IN 1903

The year 1903 must have been an exceedingly busy one for the Wright brothers. In March they applied for their first patent; on June 18 Wilbur wrote a letter stating that their engine developed 15.6 horsepower at the "brake," thus indicating its early completion; and we know that by fall they were in North Carolina making final assembly of the airplane. In addition to all this, they still found considerable time that fall to practice flying in the previous year's glider.

The year's work reached its culmination when four successful flights were made on December 17—the first, of 12 seconds duration, was made by Orville and the last and longest, 59 seconds, was made by Wilbur. Wilbur had first tried the machine 3 days earlier but, by overcontrolling, damaged the structure on landing and thus yielded the distinction of being the first man to fly a powered craft to his brother. This is all the flying that was ever done on the 1903 airplane.

From study of the design details of this machine (now on public display at the Smithsonian Institution in Washington) it is easy to note the general characteristics that are similar to the 1902 glider. The front elevators were doubled and actuated by a unique arrangement of controls such that the surfaces not only deflected in the desired direction but also changed in camber, that is, positive camber for "nose-up" and negative camber for "nose-down." The wing-warp system was retained but was refined by better routing of the control wires and the use of bellcranks. The vertical rudders were made multiple surfaces and interconnected with the wing warp as before. Note that, as always, the warp wires served not only as controls but also as structure rigging wires.

For the first time, we see cloth covering used on both the top and bottom surfaces of each wing. The wings were intentionally rigged to a 10-inch droop measured at the tips. This was the equivalent of a negative $2\frac{1}{2}^\circ$ dihedral.

The wing proportions yield on computation an equivalent monoplane aspect ratio of 3.82; and at 12 horsepower and their speed of 30 miles per hour, it appears that their L/D ratio for level flight was approximately 5.

The ship was taken off (without assist) from a 60-foot monorail. Most of the craft's weight rested on a jettisonable cradle attached to a ball-bearing hub from a shop wheel. A smaller wheel made from a bicycle-wheel hub was permanently attached to the front skid. The ship was restrained by a cable until released by the operator. A small string from the release cable pulled the fuel valve to wide-open position and then broke readily as the ship moved forward.

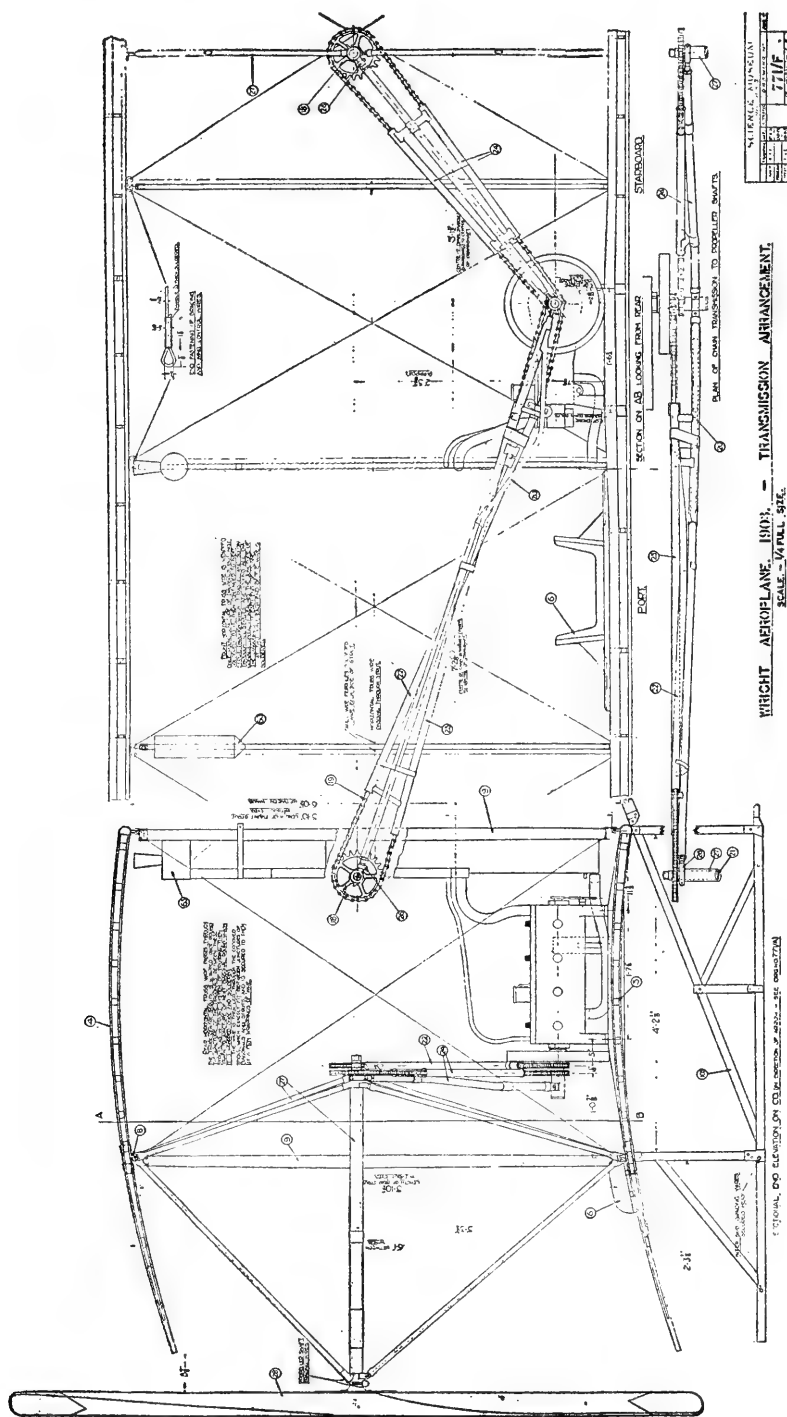


FIGURE 3.—A drawing made in England to show the 1903 power transmission by chain drive.

Throughout all their writings, the Wrights seemed to depreciate the design of their early engines, and yet, as we look over their work now, we see innumerable instances of outstanding ingenuity.

The *Kitty Hawk* had a horizontal four-cylinder engine of 4-inch bore (chosen for high displacement) and 4-inch stroke (chosen in the interest of light weight). The cylinders were individual cast-iron units fitted into a single-piece cast-aluminum crankcase that extended far enough to form a water jacket around the cylinder barrels. A camshaft driven from the crankshaft by a chain operated the exhaust valves and the individual breaker arms for cylinder firing. The intake valves were spring closed and opened by natural aspiration.

The crankshaft was machined from a solid $1\frac{9}{16}$ -inch-thick sheet of armor plate and had five babbitted main bearings. The rear end of the crankshaft was fitted with a 15-inch-diameter flywheel weighing 26 pounds and a double sprocket for driving the propeller chains. The crankshaft was lubricated by splash and strategically placed troughs. The connecting rods were tubular with bronze fittings—pinned and soft soldered—and the crank ends were babbitted. The pistons were lubricated by small engine oil cups near the end of the stroke.

The ignition for running was supplied by a low-tension horseshoe generator with induced electromotive field, driven by a contact wheel against the flywheel. A starter box, not carried in the airplane, containing four dry-cell batteries and a homemade inductance coil made by wrapping bell wire around a core of cut lengths of broom wire, furnished a hot spark for starting only. The spark timing was retarded for starting by a cam movement to advance the normal position of the camshaft sprocket, thus changing the exhaust-valve timing at the same time. Most of the "old-timers" recall that the Wrights' early engines started easily. Cooling water for the engine was supplied by thermosiphon flow from a long narrow radiator mounted on one of the center-section struts.

The fuel system involved simply gravity flow from the gasoline tank mounted near the top of one center-section strut, through a copper line leading to a shallow enclosed and baffled pan covering the four cylinders above their water jacket. There were two valves in the fuel line, the first for metering adjustment and the second for full throw between open and closed positions. The only way to stop this engine was to close this second valve. The dimensions of the fuel tank indicate an actual capacity of three-eighths gallon.

It has often been stated that the power dropped from 16 to 12 horsepower after warm-up and we can only surmise that this was due to the type of carburetion used, the inherently late intake timing, and the 15-cent kerosene-byproduct fuel that was available.

The instrumentation provided was solely for the purpose of obtaining flight records. A Veeder counter on the engine recorded total revolutions from its start until starvation took place after closing the fuel valve. A Richards anemometer, with interconnected stop watch actuated by a cord from the fuel valve, measured the air traversed in meters.

It may be interesting to note that by the old ALAM formula,

$$\text{horsepower} = \frac{D^2 N}{2.5}$$

where D is the diameter of the cylinders in inches, and N the number of cylinders, the engine's power is 25.6 horsepower.

The Wrights always said that their most difficult design problem on the first airplane was that of the propeller. Since the empirical formulas of marine propellers seemed not readily adaptable to air performance, they worked out a practical solution of their own, which was quite adequate and commendable. By taking scattered bits of formulae and notes throughout their diaries, one can reconstruct their theory and can best explain it by working out a sample computation of power required.

DEVELOPMENT WORK IN 1904 AND 1905

A second airplane was built in 1904 and tested at Dayton throughout the summers of 1904 and 1905. This airplane is of particular interest in that it was really the development step between the 1903 prototype and the "practical flyer," as Wilbur put it.

There were very few basic changes in the new wing cellule. The front elevators were made larger and moved forward 1 foot. The elevator support and skid structure was improved upon, and the rudder was raised for more ground clearance. Also, fixed vertical fins were added at the front elevators. All changes made on this machine resulted in a 105-pound weight increase over the prototype.

The engine for this airplane was basically the same except for certain improvements:

1. Bore was increased to $4\frac{1}{8}$ from 4 inches.
2. A gear-type oil pump, driven from the camshaft, was added.
3. The fuel tank was made to hold a full gallon.
4. A compression release was added to stop the engine without waiting for the fuel to exhaust. This release was in the form of a rod which pulled four small spring clips into place to hold all exhaust valves open.

Several notebook notations indicated that the engine was now developing 14.1 horsepower at 1,070 revolutions per minute and 19.8 horsepower at 1,300 revolutions per minute.

SIGNAL CORPS SPECIFICATION, NO. 486.

ADVERTISEMENT AND SPECIFICATION FOR A HEAVIER-THAN-AIR FLYING MACHINE.

TO THE PUBLIC:

Sealed proposals, in duplicate, will be received at this office until 12 o'clock noon on February 1, 1908, on behalf of the Board of Ordnance and Fortification for furnishing the Signal Corps with a heavier-than-air flying machine. All proposals received will be turned over to the Board of Ordnance and Fortification at its first meeting after February 1 for its official action.

Persons wishing to submit proposals under this specification can obtain the necessary forms and envelopes by application to the Chief Signal Officer, United States Army, War Department, Washington, D. C. The United States reserves the right to reject any and all proposals.

Unless the bidders are also the manufacturers of the flying machine they must state the name and place of the maker.

Preliminary.—This specification covers the construction of a flying machine supported entirely by the dynamic reaction of the atmosphere and having no gas bag.

Acceptance.—The flying machine will be accepted only after a successful trial flight, during which it will comply with all requirements of this specification. No payments on account will be made until after the trial flight and acceptance.

Inspection.—The Government reserves the right to inspect any and all processes of manufacture.

GENERAL REQUIREMENTS.

The general dimensions of the flying machine will be determined by the manufacturer, subject to the following conditions:

1. Bidders must submit with their proposals the following:

- (a) Drawings to scale showing the general dimensions and shape of the flying machine which they propose to build under this specification.
- (b) Statement of the speed for which it is designed.
- (c) Statement of the total surface area of the supporting planes.
- (d) Statement of the total weight.
- (e) Description of the engine which will be used for motive power.
- (f) The material of which the frame, planes, and propellers will be constructed. Plans received will not be shown to other bidders.

2. It is desirable that the flying machine should be designed so that it may be quickly and easily assembled and taken apart and packed for transportation in army wagons. It should be capable of being assembled and put in operating condition in about one hour.

3. The flying machine must be designed to carry two persons having a combined weight of about 250 pounds, also sufficient fuel for a flight of 125 miles.

4. The flying machine should be designed to have a speed of at least forty miles per hour in still air, but bidders must submit quotations in their proposals for cost depending upon the speed attained during the trial flight, according to the following scale:

40 miles per hour, 100 per cent.
39 miles per hour, 90 per cent.
38 miles per hour, 80 per cent.
37 miles per hour, 70 per cent.
36 miles per hour, 60 per cent.
Less than 36 miles per hour rejected.
41 miles per hour, 110 per cent.
42 miles per hour, 120 per cent.
43 miles per hour, 130 per cent.
44 miles per hour, 140 per cent.

5. The speed accomplished during the trial flight will be determined by taking an average of the time over a measured course of more than five miles, against and with the wind. The time will be taken by a flying start, passing the starting point at full speed at both ends of the course. This test subject to such additional details as the Chief Signal Officer of the Army may prescribe at the time.

6. Before acceptance a trial endurance flight will be required of at least one hour during which time the flying machine must remain continuously in the air without landing. It shall return to the starting point and land without any damage that would prevent it immediately starting upon another flight. During this trial flight of one hour it must be steered in all directions without difficulty and at all times under perfect control and equilibrium.

7. Three trials will be allowed for speed as provided for in paragraphs 4 and 5. Three trials for endurance as provided for in paragraph 6, and both tests must be completed within a period of thirty days from the date of delivery. The expense of the tests to be borne by the manufacturer. The place of delivery to the Government and trial flights will be at Fort Myer, Virginia.

8. It should be so designed as to ascend in any country which may be encountered in field service. The starting device must be simple and transportable. It should also land in a field without requiring a specially prepared spot and without damaging its structure.

9. It should be provided with some device to permit of a safe descent in case of an accident to the propelling machinery.

10. It should be sufficiently simple in its construction and operation to permit an intelligent man to become proficient in its use within a reasonable length of time.

11. Bidders must furnish evidence that the Government of the United States has the lawful right to use all patented devices or appurtenances which may be a part of the flying machine, and that the manufacturers of the flying machine are authorized to convey the same to the Government. This refers to the unrestricted right to use the flying machine sold to the Government, but does not contemplate the exclusive purchase of patent rights for duplicating the flying machine.

12. Bidders will be required to furnish with their proposal a certified check amounting to ten per cent of the price stated for the 40-mile speed. Upon making the award for this flying machine these certified checks will be returned to the bidders, and the successful bidder will be required to furnish a bond, according to Army Regulations, of the amount equal to the price stated for the 40-mile speed.

13. The price quoted in proposals must be understood to include the instruction of two men in the handling and operation of this flying machine. No extra charge for this service will be allowed.

14. Bidders must state the time which will be required for delivery after receipt of order.

JAMES ALLEN,

Brigadier General, Chief Signal Officer of the Army.

SIGNAL OFFICE,
WASHINGTON, D. C., December 22, 1907.

FIGURE 4.—Reproduction of the specification sheet for the first U. S. Army airplane.

The most notable features of this machine are quite well known. Briefly, they are:

1. Flight range increased to 24 miles.
2. Endurance increased to over 38 minutes.
3. Catapult used for launching.
4. Rudder operated independently. It was concurrent with, although not attributable to, this change that the Wrights learned to avoid stalls in the turn by careful use of the elevator instead of trying to correct entirely with the rudder.

PREPARING FOR THE FIRST SALE IN 1908

The years 1906 and 1907 were devoted to intense developing and testing of an airplane that would be of practical value to the United States Army. In 1908 the final form of this machine was successfully demonstrated by Orville to carry two occupants over a closed 125-mile course at a speed of 42 miles per hour.

In this machine, a new vertical engine was used to provide space for the extra passenger. The hip yoke for the wing warp was replaced by a hand lever, both occupants now sitting upright. The rudder control was not interconnected.

The engine was now equipped with four $4\frac{3}{8}$ - by $4\frac{1}{4}$ -inch cylinders, developing a maximum total of 39 horsepower at 1,600 revolutions per minute. The water jacket was no longer cast integral with the crankcase, there being individual thin-walled castings around each of the cylinders. There was still no water cooling of the heads. Ignition for starting and running was furnished by a "Mea" magneto through high-tension cable to single spark plugs. Both the magneto and the camshaft were gear-driven.

There were two gear pumps driven by the camshaft, the first an oil pump furnishing lubricant to the main bearings and the second a fuel pump. Each connecting rod had a small, drilled finger scoop for its lubrication. The engine was stopped by the compression release device used in the 1904-05 engine. An intake manifold with internal baffling conducted the fuel mixture to each cylinder. Fuel was introduced through a small jet orifice into an open air-intake tube leading into the center of the intake manifold.

CONCLUDING REMARKS

In a paper of this length it is impossible to cover all the many incidents of historical interest, the lack, it is hoped, being compensated for by a more complete recording of the steps taken to develop one of our greatest inventions from first conception to a "reduction to practice" salable machine.

The Wright brothers made mistakes in their 9 years of work to be sure and can easily be accused of doing some things the "hard way," but a serious student of their work cannot avoid developing respect for the engineering ability of these two men.

If there is a keynote to be noticed, it would best be expressed as balance. In their thinking they balanced the advantages against the disadvantages, in their measuring they balanced the unknown against the known, and in their flight instruction to others they stressed the development of a sense of balance. Perhaps it was their skill as expert bicycle riders in boyhood that influenced their way of thinking in maturity.

CHEMICAL ACHIEVEMENT AND HOPE FOR THE FUTURE¹

By LINUS C. PAULING
California Institute of Technology

The past hundred years have witnessed the transition of chemistry from an essentially empirical and descriptive science to a largely exact and theoretical one. One hundred years ago the properties of many chemical substances had been investigated, the difference between elements and compounds had been recognized, analytical chemistry had been developed to such an extent as to be a reliable tool, many methods of synthesis of inorganic and organic substances had been discovered, and the foundations had been laid for an extensive chemical industry. However, the correct atomic weights of the elements had not yet been generally accepted, so that the formula of water was still written as HO by many chemists. The idea of valence had not yet been formulated: it was not until 5 years later that the statement was first made (by E. Frankland in England) that atoms have a definite combining power, which determines the formulas of compounds. The first structural formulas for molecules were not drawn until 1858, when Archibald S. Couper introduced the idea of the valence bond; in the same year August Kekulé, in Germany, showed that carbon is quadrivalent. During the next half century chemistry developed very rapidly, to become the great science—and powerful art—that it is today.

HISTORY OF CHEMICAL THERMODYNAMICS

In 1847 J. Willard Gibbs, whom Wilhelm Ostwald has called the founder of chemical thermodynamics, was a child 8 years old. The first law of thermodynamics—the law of conservation of energy—had not yet been accepted by physicists, although Joule had recently made his determination of the mechanical equivalent of heat. It was not until a year later, in 1848, that Hermann Helmholtz recognized the importance of Joule's work and followed its implications through various problems in chemistry, physics, and biology. The second law of thermodynamics had been formulated by S. Carnot in 1824, but

¹ Reprinted by permission from *The Centennial of the Sheffield Scientific School*, Yale University Press, 1950.

it was not until 1851 that Lord Kelvin and Clausius combined it with the first law to produce the present science of thermodynamics, in its application to physical phenomena. Then, in the period between 1873 and 1878, Willard Gibbs published his great papers dealing with the application of thermodynamics to chemical phenomena. Gibbs' work put the science of chemical thermodynamics in nearly its final form; only one more great discovery remained to be made—that of the third law of thermodynamics, by W. Nernst at the beginning of the twentieth century.

Let us contrast the knowledge about a chemical reaction available in 1847 with that in 1947. In 1847 a reaction involving the conversion of certain reactant substances into certain products, such as nitrogen and hydrogen into ammonia, could be discussed only to the extent that direct experimental information, obtained by observing the reaction itself, was at hand. Only if the reactants had actually been observed to combine to form the products could the process be said to be a possible chemical reaction. The amount of heat evolved or absorbed during the reaction would have been known only if the reaction had actually taken place, and the heat evolution or absorption had been measured. The question of increasing the yield of the product could not have been discussed at all, for there was no knowledge as to whether increasing the temperature, increasing the pressure, or making other changes in the system would increase or decrease the amount of product obtained. In 1947 it was possible, from knowledge of the thermodynamic properties of the reactant substances and the products, to predict, for a reaction that has never been observed to occur, most of its important characteristics—the amount of heat that would be evolved or absorbed when the reaction takes place, and the extent to which it would take place, in its dependence on temperature, pressure, concentrations of the reactants, and other factors. There still remains, however, one most important question to which a definite answer cannot in general be given. This is the question as to the rate at which the reaction will take place under given circumstances. We are not yet able to make predictions about this rate of reaction, except for certain simple systems. The field of chemical thermodynamics is in nearly its final state of development; the field of chemical kinetics is just beginning to be developed.

Chemical thermodynamics, like nearly every other field of chemistry, has been influenced by the great progress that has taken place in the extension of our knowledge of atomic and molecular structure during the past few decades. The electron itself was discovered in 1897, and the atomic nucleus in 1911; since then a penetrating and detailed understanding of the electronic and atomic structure of matter has been obtained, and chemists are now able to talk about the

electronic and atomic architecture of molecules and crystals almost as confidently as architects can talk about the structural elements of skyscrapers and bridges. By the methods of spectroscopy, X-ray diffraction, and electron diffraction accurate interatomic distances have been determined for thousands of substances. The magnitudes of the forces operating between the atoms have also been determined experimentally for very many molecules and crystals. Further information about the nature of substances has been obtained by the application of many different techniques of modern physics—the study of the diamagnetic, paramagnetic, and ferromagnetic properties of the substances, their electrical properties, and the spectroscopy not only of the visible, infrared, X-ray, and ultraviolet regions, but even, in recent years, of the microwave and long-wave radio regions of the spectrum. The structural knowledge obtained in this way about molecules permits the calculation of thermodynamic properties for many substances.

A significant start has already been made on the task of formulating a complete system of chemical thermodynamics of pure substances. This task involves the determination for each substance at one temperature of its enthalpy, relative to the elements that compose it. It is further necessary to determine the entropy of the substance at one temperature, which can be done by any one of three methods: the measurement of a chemical equilibrium involving the substance and other substances of known thermodynamic properties, the measurement of the heat capacity down to very low temperatures and the application of the third law of thermodynamics, or the calculation of the entropy from structural data obtained by spectroscopic and diffraction methods. Knowledge of the heat capacity of the substance over a wide range of temperatures, obtained either by direct experiment or by calculation from known structural properties, then permits the extension of the tables of thermodynamic properties over this temperature range. It may well be expected that at some time in the distant future there will be available extensive tables of the enthalpy, entropy, and free energy of thousands of substances over wide ranges of conditions. There would then still remain, however, the problem of the thermodynamic properties of solutions, for which no such simple and inclusive set of data could be formulated.

It is interesting to note that, in a practical sense, the third law of thermodynamics differs from the first and second laws, in that it cannot be applied completely independently of structural considerations. In general, thermodynamic deductions are expected to be independent of any structural considerations, and to be reliable, provided only that true thermodynamic equilibrium has been approximated or achieved in the experiment. Investigations carried out

during the past 25 years, especially by Prof. William F. Giauque, have shown, however, that the applications of the third law of thermodynamics to the calculation of entropy values for crystalline substances by measurements of heat capacity made at low temperatures are often not reliable in practice, unless there is available some structural information about the residual entropy of the crystals at the lowest temperatures at which measurements are made. Thus some simple substances, such as hydrogen, carbon monoxide, nitrous oxide, and nitrogen dioxide, have residual entropies of significant amount, caused by such structural features as a randomness of orientation of molecules in the crystal lattice. It may be said, with justice, that the experiments have not yet been carried out to sufficiently low temperatures, or that sufficient time has not been allowed for the crystals to achieve a state of true thermodynamic equilibrium; nevertheless, the practical problem still exists—the reliable application of the third law of thermodynamics requires a penetrating understanding of the structure of the crystalline substance under investigation.

The recent decades have seen an extraordinary development of the art of cryogenics, the production of low temperature. The pioneer work of Dewar was extended by Kamerlingh Onnes, whose feat of reaching a temperature as low as 0.71°K . seemed for many years to be incapable of significant betterment. Then, in 1924, Giauque suggested and later put into practice the astounding new method of cooling by demagnetization, with which he and other investigators have been able to reach temperatures as low as about 0.001°K .

Although the production of low temperatures might well be considered to be a part of the science of physics, the fact that this final great achievement of reaching the temperature of 0.001°K . was made by a professor of chemistry, using a method invented by himself, justifies mention of it in this discussion. The work done by Professor Giauque illustrates the fact that the border line between chemistry and physics is a difficult one to define, as is also the border line between chemistry and biology. The logarithmic dependence of certain thermodynamic quantities on temperature is, of course, responsible for the great difficulty found in decreasing the temperature by successive factors of 10, and leads to the theorem of the impossibility of reaching the absolute zero itself. It has recently been pointed out to me by Prof. Franz Simon at Oxford, however, that it is not true that there is an interesting portion of nature to which access is denied to man, namely, the portion of nature that deals with the properties of matter at temperatures lower than those that can ever be achieved in the laboratory. Professor Simon points out that the only low-temperature range that is inaccessible to man is that in which no interesting phenomena occur, because if any phenomena were to occur, they them-

selves could be used as the method of achieving the low temperature.

Let us now return to the basis of chemistry—the atoms of the chemical elements. The last hundred years have seen the systematization of the elements through the periodic system of Mendeleev, the assignment of precise atomic weights to most of the known elements, the discovery of the elements predicted by the unfilled sequences in Mendeleev's table, as well as the unanticipated series of noble gases, and, finally, in recent years, the development of modern alchemy, the conversion of one element into another, and the artificial production of new elements. Now that four transuranium elements have been reported—neptunium, plutonium, americium, and curium—we may look forward with confidence to the announcement that still more new elements have been made,² and that practical methods of manufacture in large quantities of the most rare of the lighter elements have also been developed. We may well expect that in the future world nuclear chemistry will be found of the greatest value in many ways, not only in the production of new elements and in the use of radioactive elements as tracers, but also in causing new chemical reactions through bombardment with high-energy particles.

INORGANIC CHEMISTRY

Inorganic chemistry has been making steady progress. The inorganic chemist of today has a great advantage over his fellow of preceding generations, in that he has a thorough understanding of the molecular structure of most of the substances with which he is working, and of the relation between the physical and chemical properties of the substances and their structures. An illustration of the usefulness of structural knowledge is provided by the recent development of substances that are similar to organic compounds, but with silicon atoms, which form the same tetrahedral bonds as carbon, in place of some or all of the carbon atoms.

The first substance of this nature was made half a century ago. It had not been found possible to make in large quantities the substance diamond, which is a very useful material because it is the hardest of all known substances. However, it was found possible to make a new substance with the same tetrahedral structure as diamond, but with half of the carbon atoms replaced by silicon atoms—the substance silicon carbide, which has now for many years found extensive use as an abrasive. Then it was found that other compounds of silicon could be made, the silicones, which have, in place of long chains of carbon atoms, chains of silicon atoms (usually with oxygen atoms interspersed, in a sort of ether linkage), with methyl groups or other side

² The manufacture of two more transuranium elements, berkelium and californium, was announced early in 1950.

chains attached. The silicones have many very useful properties. They can be used as insulating lacquers, permitting electrical motors to be built for operation at much higher temperatures than with organic insulators. Silicone rubber can be made, especially for use at higher temperatures than those withstood by ordinary natural rubber or synthetic rubber. Some of the silicone oils have a very valuable property, that of changing their viscosity only a small amount with change in temperature—a property that seems to be due to the tendency of the molecules to coil into a roughly spherical shape at low temperatures, and hence to roll over one another relatively easily, whereas at higher temperatures, at which the molecules uncoil, they become entangled with one another, and thus overcome in large part the normal tendency of a liquid to show a pronounced decrease in viscosity with increase in temperature.

The chemistry of fluorine has made great progress in recent years. The valuable properties of new compounds of fluorine depend on the volatility of fluorine compounds and the low chemical reactivity of the carbon-fluorine bond. Useful fluorine compounds include the freons, such as CF_2Cl_2 , which are used as the fluid in refrigerating machines and as nontoxic solvents for insecticides and other solutes, and the fluorine-carbon high polymers, such as the extremely unreactive plastic that is formed by the polymerization of tetrafluoroethylene.

An interesting recent development in inorganic chemistry is that of new techniques for growing large crystals for special purposes. During the war it was found possible to grow large crystals, weighing many pounds, of such substances as ethylenediammonium tartrate, valuable because of their piezoelectric properties, which find use in radar and other fields of modern physics. In Germany, an interesting technique of growing large crystals of synthetic mica was developed, a technique which depends for its success on the orientation of the growing crystal in a strong magnetic field.

ORGANIC CHEMISTRY

The art of organic chemistry and the science of organic chemistry have moved along steadily hand in hand. Organic chemists develop a feeling for the chemical properties of the many substances with which they work which goes far beyond the systematized theoretical knowledge that they can express; but the theory of organic chemistry has nevertheless now developed to such a state that the science is no longer a mysterious one, purely an art whose practice depends on the application of empirical rules. It is now possible for the organic chemist to use his knowledge of molecular structure to predict, with some confidence, that certain reactions could be carried out to produce products with certain desired properties. One most interesting appli-

cation of this new method in organic chemistry has been to the manufacture of high polymers, such as the new fibrous and plastic substances, which were synthesized in consequence of predictions of their properties made upon the basis of considerations of molecular structure.

The methods used by the organic chemist become more powerful from decade to decade. He now has at hand techniques of very high-pressure hydrogenation, the use of catalysts specific to certain reactions, powerful techniques of separation such as chromatographic analysis and molecular distillation, and new physical methods for structural studies such as X-ray diffraction and spectroscopy. A very interesting example of the interrelation between organic chemistry and other fields was provided during the war by the concerted attack on the problem of the structure of penicillin. The organic chemists who were working on the problem found it impossible to determine the correct structure by the conventional methods, because the molecule has some structural characteristics that had not appeared before in any known substances, and it remained for physical chemists and physicists, using the techniques of X-ray diffraction and infrared spectroscopy, to determine the structure for them.

CHEMISTRY IN RELATION TO BIOLOGY AND MEDICINE

It is the field of chemistry in relation to biology and medicine in which most striking progress has been made in recent decades, and which offers the most promise for the future. Biologists now are becoming chemists; they isolate vitamins, hormones, enzymes, acetylcholine in nervous processes, histamine in anaphylaxis and allergic responses, plant-growth factors, wound-healing substances, flowering substances, substances to hold the fruit on the trees and to ripen the fruit after it has left the trees. No longer is it possible for a chemist to achieve a feeling of superiority to the biologist simply by quoting some complex chemical formulas—nor, indeed, for the physicist to overcome the chemist by quoting some complex mathematics.

And in medicine, as in biology, a new future is drawing near—a future of great progress through ever closer cooperation with the basic sciences. There has been great progress in medicine during the past century. In 40 years the mean expectancy of life has increased from 49 to 65 years. Mortality from childhood diseases—diphtheria, scarlet fever, whooping cough—has decreased in 25 years to 10 percent of its previous value. Other infectious diseases are in the main well under control by vaccines, serums, the sulfa drugs, and now penicillin. Shakespeare mentioned "the rotten diseases of the south, the guts-griping, ruptures, catarrhs, loads o'gravel i' the back, lethargies, cold

palsies, raw eyes, dirt-rotten livers, wheezing lungs, bladders full of imposthume, sciaticas, lime-kilns i' the palm, incurable bone-ache, and the riveled fee-simple of the tetter." Most of these diseases are no longer important: there are now no serious cases, so far as I know, of riveled fee-simple of the tetter, but "incurable bone-ache," under which we might include arthritis, is a very serious disease, of which little control has been obtained. There are still virus diseases that are very troublesome—poliomyelitis, influenza, the common cold. Then there remains the problem of the degenerative diseases—cancer, heart disease, cerebral disease, nephritis—which, as control of other diseases is obtained, are becoming increasingly important. To attack these great medical problems new basic knowledge is needed about the nature of cells and of physiological processes, and about the chemotherapeutic action, as well as the normal physiological action, of chemical substances.

STRUCTURAL BASIS OF PHYSIOLOGICAL ACTIVITY

The greatest problem that remains to be solved is that of the structural basis of the physiological activity of chemical substances. When once this problem has been solved, and when it has become possible to determine in detail the molecular structure of the vectors of disease and of the constituents of the cells of the human body, we shall be able to draw up the specifications of the specific therapeutic agent to protect the body against a specific danger, and then to proceed to synthesize the agent according to the specifications. So far, we have only the hint that chemotherapeutic agents may act through competition with essential metabolites, as in the competition, pointed out by Woods and Fildes, of the sulfa drugs with *p*-aminobenzoic acid.

I believe that this problem—that of the nature of the competition of two substances presumably for specific combination with some part of a living cell—is very closely related to the general problem of the nature of the forces that lead to the striking specificity of properties shown by many biological substances, especially the native proteins and polysaccharides. I believe that these forces are also operative in the phenomenon of self-duplication shown by viruses, genes, and other biological entities. I myself have been especially interested in the specific forces operating between an antibody molecule and the molecules of antigens or haptens with which it has the power of specific combination. My interest in this problem was developed over 10 years ago in conversations with Dr. Karl Landsteiner, and the work that my collaborators and I have done has consisted largely in the extension and refinement of investigations initiated by Dr. Landsteiner.

Let us review briefly the basic phenomena of immunochemistry. When a foreign material of large molecular weight—a protein or

polysaccharide, either pure or part of the structure of an animal or plant cell—is injected into an animal, such as a rabbit, the animal in the course of a few days may develop in its blood and within its cells substances called antibodies which have the power of specific combination with the injected material, the antigen. Thus, when a particular animal or plant protein is injected into a rabbit, the rabbit develops in its blood antibodies which are capable of combining with that protein, but not, or at any rate only very exceptionally, capable of combining with any of the tens of thousands of other proteins which exist in nature. For example, an antiserum made by injecting hemoglobin obtained from one animal into a rabbit is able to combine with that form of hemoglobin, but not with hemoglobin obtained from the red cells of other animals, except those of very closely related species. The act of combination of antibody and its homologous antigen may be shown by several different phenomena, such as the agglutination of cells, in the case of a cellular antigen, the formation of a precipitate on mixing a solution of antigen and its homologous antibody, the allergic response of a sensitized animal on receiving a subsequent injection of the antigen, and the lysis or other changed behavior of cells to which antibody has attached itself.

The phenomena of immunochemistry raise two great questions. The first concerns the nature of the forces between antibody and antigen, which lead to the power of selective combination of antibody and the homologous antigen and the rejection of other molecules, except those very closely related to the homologous antigen. The second problem is that of the mechanism of the manufacture of the antibody, and of its endowment with this power of specific combination.

The great versatility of living organisms in their production of specific antibodies was shown by the early work of Landsteiner with artificial conjugated proteins as antigens. Landsteiner found that it was possible to cause an animal to make antibodies with the power of specific combination with various chemical substances of known structure. He achieved this by attaching these chemical substances to a protein molecule, which was then injected into a rabbit. The rabbit, under the influence of the injected protein, produced an antiserum containing antibodies capable in general of combining with the particular protein that was used in making the artificial conjugated protein, and also capable of combining with the attached chemical substances. For example, an antiserum prepared by coupling diazotized *p*-aminobenzenearsonic acid with ovalbumin was found to form a precipitate with this particular azoprotein, and in addition to precipitate, in smaller amounts, ovalbumin itself and also any azoprotein made by coupling diazotized *p*-aminobenzenearsonic

acid with another protein, such as sheep serum albumin. The precipitation by the antiserum of such an azoprotein, in which the protein part is completely different from that of the immunizing azoprotein, is evidence that some of the antibodies in the antiserum have a specific combining power with the benzenearsonic acid group. Landsteiner and his collaborators were able in this way to prepare antisera containing antibodies with the power of specific combination with scores of different chemical substances, many of which could hardly be considered to have any natural relation to the injected animal. These results showed that the versatility of the living organism in antibody production is very great, and made it probable that the antibody precursor is to be considered as a plastic material, able to be influenced by the injected antigen in such a way as to obtain directly from the antigen itself the property that leads to the power of specific combination with it.

Landsteiner and his collaborators also discovered and utilized an important phenomenon, that of hapten inhibition. They found that, for example, when benzenearsonic acid itself is added to an antiserum made by injecting an azoprotein containing the *p*-azobenzenearsonic acid group no precipitate is formed. Nevertheless, it can be deduced that combination has occurred between the benzenearsonic acid and the antibody, because on addition of an azoprotein containing the *p*-azobenzenearsonic acid group no precipitate occurs, although a precipitate would be formed in the absence of the benzenearsonic acid. The benzenearsonic acid is thus shown to have the power of combining with antibody homologous to this haptenic grouping, to form a soluble complex. Information about the strength of the combination of the hapten and of the antibody can be obtained by seeing what concentration of hapten is necessary to prevent the precipitation of the antiserum with a hapten-homologous azoprotein. Landsteiner and his collaborators in this way obtained a great amount of qualitative information about the combining powers of various chemical substances with antibodies homologous to haptenic groups of known structure. They found, for example, that not only benzenearsonic acid but also various substituted benzenearsonic acids have the power of combining with anti-*p*-azobenzenearsonic acid serum, and that the strength of the combination depends upon the nature of the group substituted in the benzene ring and on the position in which it is substituted. Thus, in general, a group substituted in the para position in benzenearsonic acid increases the combining power with anti-*p*-azobenzenearsonic acid serum, whereas the substitution of a group in the ortho or meta position decreases the combining power with these antibodies.

My collaborators³ and I have outlined and extended this work, primarily by developing and using quantitative methods, permitting the determination of approximate values for the equilibrium constant of the reaction of combination of hapten and antibody. We have also made use of a simplification in the experiments, involving the elimination of one protein from the precipitation test. Inasmuch as the structure of no protein is as yet known, a precipitation reaction involving two proteins, the antibody and the azoprotein, is an especially complicated reaction to study, and the possibility of obtaining information about the antibody might well become greater if the other protein could be eliminated. Landsteiner and van der Scheer observed that certain simple substances that they had prepared for use as hapten inhibitors themselves gave a precipitate with the hapten-homologous antisera. These substances were dyes obtained by coupling two or more haptenic groups together; an example is resorcinol with two or three azobenzenearsonic acid groups attached to it. Many of our hapten-inhibition experiments have been performed with use of precipitating polyhaptenic antigens of this type, the system under study then containing only one substance of unknown structure, the antibody itself.

COMPLEMENTARINESS IN STRUCTURE

Landsteiner's results could be interpreted in terms of our modern knowledge of atomic and molecular structure to permit a definite conclusion to be reached regarding the nature of the specific forces between antibody and antigen and the structure of antibody molecules, and this conclusion has been strengthened by the additional information given by the experiments that my collaborators and I have performed in Pasadena. The conclusion is that the specificity of interaction of antibody and homologous antigen results from a detailed complementariness in structure, as was first suggested by Haurowitz and Breinl and by Jerome Alexander, and later emphasized by Stuart Mudd.

The complementariness in structure must be such as to permit a large portion of the surface of the antigen to be brought into juxtaposition with a corresponding portion of the surface of the antibody molecule. The weak forces that operate between any atom or small atomic group and adjacent atoms would then come into operation between each surface atom of the antigen and the immediately adjacent atoms of the antibody; these weak forces, integrated over the juxtaposed surfaces, would produce a resultant force strong enough to lead to the formation of an effective bond. Inasmuch as most of the weak

³ Prof. Dan H. Campbell, David Pressman, Carol Ikeda, Miyoshi Ikawa, David H. Brown, John T. Maynard, Allan L. Grossberg, Stanley M. Swingle, John H. Bryden, Leland H. Pence, and Frank Lanni.

forces operating between atoms and small molecules fall off very sharply with increasing distance, an effective bond would be formed only if the two molecules were in contact with one another, that is, if the surfaces of the atoms of antigen and antibody were no more than a very few angstroms apart. The specificity of the bond formed in this way would result from the detailed complementariness not only in general surface configuration but also in the position of the groups capable of forming hydrogen bonds and in the positions of the positive and negative electrical charges. It can readily be seen that this mechanism does provide the possibility of very great specificity. Thus a combining region with area of perhaps 200 square angstroms, representing a surface of about 50 atoms, could be prevented from approaching to contact with the complementary region on the antibody simply by replacing a methyl group, say, on the antigen surface by a phenyl group, which would extend about 3 Å. above the former surface, and would hence hold the antibody 3 Å. farther away from the antigen, thus reducing the forces of attraction to such an extent as no longer to permit them to result in a significant bond.

The approximation of the antibody to the haptenic group of the immunizing antigen must be very close. A striking bit of evidence, from among the great amount that exists, is that of the cross reactivity of two closely related haptenic groups, the *m*-aminobenzoic acid group and the 4-chloro-3-aminobenzoic acid group, which differs from the first only in having a chlorine atom in place of the hydrogen atom. Landsteiner and his collaborators found that anti-4-chloro-3-aminobenzoic acid serum precipitates readily both with the hapten-homologous azoprotein and with an azoprotein containing the *m*-azobenzoic acid group. On the other hand, the anti-*m*-azobenzoic acid serum precipitates readily an azoprotein containing the *m*-azobenzoic acid group, but does not form a precipitate with an azoprotein containing the 4-chloro-3-azobenzoic acid group. The explanation that we propose of this cross reactivity between one antiserum and the substituted azoprotein, but not between the other antiserum and the different azoprotein, is that the phenomenon depends upon the fact that the chlorine atom is much larger than the hydrogen atom that it replaces, the van der Waals radius of chlorine being about 1.8 Å. and that of hydrogen only about 1.2 Å. If it is assumed that the combining region of an antibody fits tightly about the haptenic group of the immunizing antigen, the anti-4-chloro-3-azobenzoic acid antibodies would contain in the appropriate place a cavity into which a chlorine atom could fit, along with the rest of the haptenic group. This cavity, with radius 1.8 Å., would be large enough to accept easily a hydrogen atom in the unsubstituted azoprotein, and the replacement of chlorine by hydrogen would have no effect other than to decrease slightly the force of

attraction between the haptenic group and the antibody, as a result of the smaller van der Waals attraction of a hydrogen atom and of a chlorine atom for surrounding atoms. On the other hand the cavity in the anti-*m*-azobenzoic acid antibody is required only to be large enough to receive a hydrogen atom, with van der Waals radius 1.2 Å. There might well then be a considerable amount of steric strain if the 4-chloro-3-azobenzoic acid haptenic group were to be forced into this cavity in the antibody, and the steric strain might be great enough to decrease the combining power to such an extent that no precipitate would be observed by the investigators.

This experimental result indicates that the fit of antibody to antigen is, in some cases at least, a very close one, so that a difference in atomic radius of 0.6 Å. is significant. Our quantitative investigations in Pasadena provided a large amount of evidence substantiating this conclusion. One extensive series of investigations was made of the combination of antisera homologous to the *o*-benzenearsonic acid haptenic group, the *m*-azobenzenearsonic acid group, and the *p*-azobenzenearsonic acid group. It was found that in each case the substituted benzenearsonic acids with the substituent in the same position as the azo group of the immunizing azoprotein combine more strongly with the antibody than those with the substituent group in a different position, and the conclusion was reached from the values of the hapten inhibition constant that the surface configuration of the combining regions of the antibody molecules approximates that of the haptenic group to within closer than 1 Å. A similar conclusion has also been reached by a study of the effect of electrical charge. The ratio of inhibiting powers of two similar haptens, one containing a positively charged group, the trimethylammonium ion group, and the other an uncharged group with the same size and shape, the tertiary butyl group, with antiserum made by injecting rabbits with sheep serum with attached *p*-azobenzene-trimethylammonium ion groups could be interpreted to show that the positive charge of the charged haptenic group interacts with a negative charge in the antibody 7 Å. away. Inasmuch as the positive charge in the phenyltrimethylammonium ion may be considered to be at the center of the nitrogen atom, and the radius of this ion (the distance from the center of the nitrogen atom to the surface of the methyl groups) is 3.5 Å., and inasmuch as the minimum distance of approach of a negative charge to the surface of the antibody may be taken as the radius of an oxygen atom, 1.4 Å., the minimum distance of approach of a positive charge in the hapten and a negative charge in the antibody is calculated to be 4.9 Å. The fact that the value calculated from the hapten-inhibition data is only 2.1 Å. greater than this again indicates that in general there is a very great complementariness in structure and closeness of fit of antibody and antigen.

It is my opinion that the general problem of the nature of specific biological forces has thus been solved, and that with the extension of our knowledge of the detailed atomic structure of proteins and other biological substances we may hope that this understanding will permit a more effective attack to be made on many of the problems of biology and medicine.

NATURE OF ENZYMES

I should like now to discuss a closely related question: the nature of enzymes and of catalysts in general. In order to function, the living cell carries out many specific chemical reactions that do not take place when the reactants are simply mixed with one another. These reactions occur in nature because there are present molecules of a specific catalyst, the enzyme appropriate to the reaction. I believe that an enzyme has a structure closely similar to that found for antibodies, but with one important difference, namely, that the surface configuration of the enzyme is not so closely complementary to its specific substrate as is that of an antibody to its homologous antigen, but is instead complementary to an unstable molecule with only transient existence, the "activated complex," for the reaction that is catalyzed by the enzyme.

The mode of action of an enzyme would then be the following: the enzyme would show a small power of attraction for the substrate molecule or molecules, which would become attached to it in its active surface region. This substrate molecule, or these molecules, would then be strained by the forces of attraction for the enzyme, which would tend to deform it into the configuration of the activated complex, for which the power of attraction by the enzyme is the greatest. The activated complex would then, under the influence of ordinary thermal agitation, either reassume the configuration corresponding to the reactants, or assume the configuration corresponding to the products. The assumption made above that the enzyme has a configuration complementary to the activated complex, and accordingly has the strongest power of attraction for the activated complex, means that the activation energy for the reaction is less in the presence of the enzyme than in its absence, and accordingly that the reaction would be speeded up by the enzyme. My colleague Prof. Carl Nie-
mann and I are carrying out experiments on inhibition of enzyme activity designed to test this postulate, by the search for inhibitors that have a greater power of combination with the enzyme than have the substrate molecules themselves. This method of attack should, indeed, provide us with information about the nature of the active region of the enzyme, if we accept the postulate that it is complementary to the configuration of the strong inhibitors.

This picture of the nature of enzymes may well make us optimistic about the future of chemotherapeutics, for it predicts that for every enzyme, and in particular for the enzymes that are essential for bacterial growth, it would be possible to find an inhibiting molecule which is more closely complementary in structure to the enzyme than is the substrate itself, and which would accordingly be an effective inhibitor. The picture even presents us with an idea as to the nature of substances which would be effective inhibitors, namely, that these substances should closely resemble the activated complex, intermediate in configuration between the reactants and the products of the catalyzed reaction. A possible practical application of this concept is in relation to penicillin and its destruction by the enzyme penicillinase. Some of the organisms that resist the bacteriostatic action of penicillin may achieve their resistance through the manufacture of penicillinase, which destroys the penicillin as it approaches the organism. If it were possible to synthesize or to obtain by the degradation of penicillin itself a substance with molecular configuration such that it would combine with penicillinase more strongly than does penicillin, and thus would inhibit the action of the penicillinase, this specific inhibitor might be injected (or even taken by mouth) along with the penicillin, which might in this way increase its bacteriostatic action.

FORMATION OF SPECIFIC ANTIBODIES

We have far less evidence bearing in a detailed way on the problem of the process of formation of complex biological molecules than on the problem of the nature of specific biological forces. Nevertheless, a reasonable proposal can be made as to the process of formation of these molecules, on the basis of the information available on the nature of the forces themselves, and the assumption that the known laws of molecular physics are applicable to biological systems. I shall illustrate this proposal by discussing a possible mechanism of formation of specific antibodies.⁴

The problem that we pose is the following: How is it possible for a cell to manufacture an antibody molecule with the power of specific combination with an arbitrarily chosen antigen? It might be that the difference in structure of the antibody molecule and a normal molecule of γ -globulin or an antibody molecule homologous to another antigen would result from a difference in the ordering of the amino acid residues in the polypeptide chains, as was suggested by Breinl and Haurowitz, and by Mudd.⁵ However, a simpler assumption is that all antibody molecules produced by the same protective

⁴ Pauling, L., *Journ. Amer. Chem. Soc.*, vol. 62, p. 2643, 1940.

⁵ Breinl, F., and Haurowitz, F., *Zeitschr. Physiol. Chem.*, vol. 192, p. 45, 1930; Mudd, D., *Journ. Immunol.*, vol. 23, p. 423, 1932

mechanism in the cell contain the same polypeptide chains as the normal globulin and differ from normal globulin and each other only in the configuration of the chain, that is, in the way the chain is coiled in the molecule. It is much easier to devise a mechanism for causing the polypeptide chain to assume the desired one of the alternative configurations than to devise a mechanism for producing great variations in the ordering of the amino acid residues. Moreover, the number of configurations accessible to a polypeptide chain containing a thousand or more amino acid residues is so great as to provide an explanation of the ability of the animal to form antibodies capable of specific combination with a very great number of different antigens.

Let us assume that a portion of a polypeptide chain (one end, say) which would be involved in the formation of a combining region of the antibody is of such a nature that it is able to coil into any one of a large number of alternative configurations, all of which have very nearly the same energetic stability, so that the choice among them may be determined by relatively small changes in the environment, tending to stabilize one or another of the configurations. In the absence of an antigen the polypeptide chain would fold into the configuration that happens to be the most stable in the environment in the cell, and would produce a molecule of normal γ -globulin. In the presence of the antigen, however, the folding of the polypeptide chain would take place in a way determined to some extent by the interaction of the chain with the atoms in the surface of the antigen molecule. This interaction would find expression in the formation of that configuration or those configurations of the polypeptide chain that permit the system as a whole to have the greatest stability. The greatest stability results, of course, from the formation of the strongest bond between the folded polypeptide chain and the antigen molecule. Accordingly, we have in this simple mechanism, involving the folding of a polypeptide chain into a structure whose nature is determined in considerable part by the presence of an antigen in the immediate neighborhood, a straightforward way of producing an antibody molecule with the power of specific combination with the particular antigen present, resulting from a complementariness in structure that is automatically assumed by the polypeptide chain that constitutes the combining region of the antibody molecule.

It is clear that the same mechanism, whereby one molecule present in the cell may influence the structure of another molecule that is being formed, may be invoked as an explanation of both heterocatalytic and autocatalytic activities of biological molecules in general. A gene may have the power of causing the synthesis of a certain protein molecule capable of acting as an enzyme catalyzing a particular chemical reaction through its possession of a structure essentially complementary to that of the active region of the enzyme molecule,

and which can act as a template in the production of that enzyme molecule. The power of self-duplication of the gene might well have a similar explanation. In case the gene happens to be complementary to itself, then it could serve directly as the pattern for itself; or it might produce the same result, the manufacture of replicas of itself, by working through an intermediate complementary to itself, which then serves as the pattern for the new gene, complementary to the intermediate and identical with the original gene. However, reliable information about the detailed nature of these fundamental molecular processes in biological systems must await further experimental study.

THE FUTURE

This discussion has been confined to the least interesting aspects of the developments of chemistry in the future. These least interesting aspects are those that can be predicted, that can be foreseen on the basis of our present knowledge. They consist primarily of the results of application and development of the discoveries that have already been made. The great discoveries of the future—those that will make the world different from the present world—are the discoveries that no one has yet thought about, the discoveries that will in fact be made as soon as the ideas underlying them take shape in the mind of some imaginative scientist. Who is there among us who 10 years ago would have predicted that the field of nuclear structure and atomic energy would develop in the way that it has? Who can now say what the great discoveries of the next 10 years will be?

I have spoken of hope for the future—but the discoveries that we cannot foresee may not all be obviously beneficial. Let me say, with Walt Whitman,

I know I am restless and make others so,
I know my words are weapons full of danger, full of death,
For I confront peace, security, and all the settled laws, to unsettle them. . . .

And the threat of what is call'd hell is little or nothing to me,
And the lure of what is call'd heaven is little or nothing to me;
Dear camerado! I confess I have urged you onward with me, and still urge you,
without the least idea what is our destination,
Or whether we shall be victorious, or utterly quell'd and defeated.

Science cannot be stopped. Man will gather knowledge no matter what the consequences—and we cannot predict what they will be. Science will go on—whether we are pessimistic, or are optimistic, as I am. I know that great, interesting, and valuable discoveries can be made and will be made, of the sort that have been here described. But I know also that still more interesting discoveries will be made that I have not the imagination to describe—and I am awaiting them, full of curiosity and enthusiasm.

ELECTROENCEPHALOGRAPHY¹

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[With 1 plate]

The classical philosophers took so little interest in the brain that they referred to it merely as "the thing in the head." Until the last century it was considered as providing a sort of radiator for overheated animal spirits; only in the last generation has the study of brain function developed into a serious science. Microscopical examination of the brain tissue revealed that it contains about 10^{10} nerve cells arranged in complex and systematic three-dimensional patterns. Electrical stimulation of the exposed brain and observation of the resulting movements and subjective sensations demonstrated the anatomical connection between some parts of the brain and various regions of the body, and it was found that, even when inactive, the brain consumes an enormous quantity of energy in relation to its size. Only in the last 20 years, however, has it been possible to study any aspect of brain function directly in the intact human subject. It had been known for a long time that communication between individual nerve cells is maintained by brief electrochemical discharges along nerve fibers, but it was not believed that electrical activity of the brain could be detected without placing electrodes directly on the exposed nerve tissue until Berger demonstrated this possibility in 1928. A record of the electrical brain activity obtained in this way with electrodes on the scalp is called the electroencephalogram or E. E. G.

Such records show continuous electrical activity of an extremely complex nature, consonant with the huge number of nerve cells and the intricacy of behavior patterns. As recorded through the scalp and skull, the potential differences of the electrical discharges are only a few millionths of a volt and have to be amplified with specially designed electronic devices that convert them into a continuous graph drawn on paper. The possibility of studying the normal brain in this way encouraged both clinical developments and the theoretical con-

¹ Reprinted by permission from *Endeavour*, vol. 8, No. 32, October 1949

sideration of brain function as a whole. Present concepts can be summarized most concisely by stating that the general function of the brain is to construct and contain a working model of the outside world, and to test upon this model the effect of the operations that circumstances suggest are necessary for comfort or survival. The more accurate and detailed the model, the more trustworthy will be the forecast of the results of action, and the better the chances of survival of the organism. In the human brain, the working parts of the model are the circuits that link the nerve cells; since their permutations are of the order of $10^{10,000}$ there seems ample scope for detail—and for fantasy.

The notion of the brain as a signal analyzer and statistical predictor has developed parallel with the design and construction of the various large computing engines sometimes known as electronic brains, but it must be admitted that as yet very little is known of the precise manner in which the animal brain composes its models so that they are compact enough to be portable, plastic enough to be changed from second to second, yet durable enough for a lifetime. It may be mentioned, however, that in man the purely nervous model is totally inadequate for social life, and is supplemented by external patterns in the form of written records, laws, and so forth. The neurophysiologist, then, would use the term "mind" as meaning the individual's model of his environment and "thought" as a miniature rehearsal for action. Such generalizations are bound to reawaken many ancient philosophical controversies, but have the virtue of promising linkage between brain physiology and other human interests, some of which will be considered later.

Returning to the discoveries in the field of electroencephalography, it was found at an early stage that recognizable perturbations of the electrical patterns occur in diseases of the brain. This observation had the unfortunate effect of distracting attention from fundamental problems, so that most laboratories engaged in this sort of work were soon full of records from epileptics and patients with brain tumors, and, during the war, with head injuries and abscesses. The literature of the subject contains thousands of papers and reports describing empirical correlations between various E. E. G. features and brain diseases, but of these publications only a few dozen are of fundamental importance, and there is no doubt that the great discoveries are still to be made.

Records from normal people show a great variety of more or less irregular electrical discharges from all parts of the brain, but in most subjects, when the eyes are shut, the discharges become more rhythmic in the occipital region, where visual impressions are projected. These regular oscillations are known as alpha rhythms and have a frequency

of between 8 and 13 cycles per second. Even with the eyes shut, some alpha rhythms are usually diminished when the subject thinks hard, and some are blocked when a vivid visual image is called up. There is wide variation between individuals, but the general picture in a given subject is very constant and is almost like a signature (figs. 1 and 2). It is important to note the paradoxical inverse relation between the prominence of the alpha rhythms and the level of functional activity and attention. In babies, there is little alpha activity; there are only much slower swings of electric potential in all areas (fig. 3). In older children, rhythms at about 6 cycles per second are prominent up to the age of 7 or 8 (fig. 4), but the alpha rhythms are beginning to appear, and the adult pattern is usually established by the age of 12. The 6-cycles-per-second activity is sometimes called theta rhythm; it

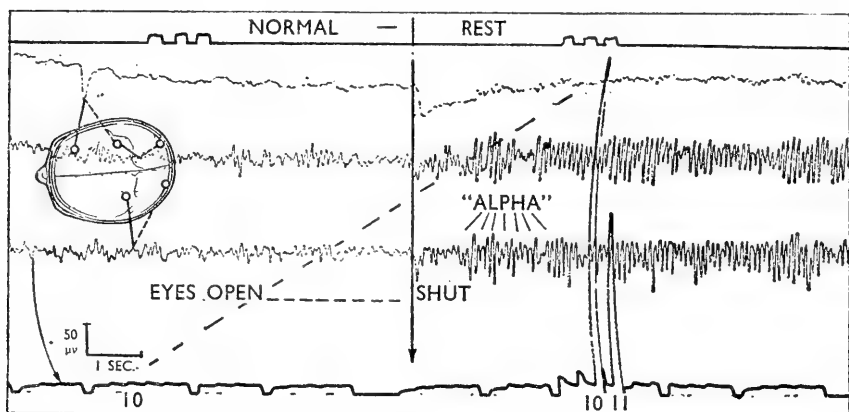


FIGURE 1.—Electroencephalogram from a normal person showing the effect of closing the eyes. Note the increase in alpha activity at 10 cycles per second in both occipital regions and the associated peak at 10 in the frequency analysis (shown in bottom line of graph).

is often larger when the child is unhappy or angry. It comes from the temporal lobes of the brain and deeper regions, and is found in many adults whose behavior is childish in the sense that they are short-tempered, aggressive, and hard to get on with.

In sleep, the alpha rhythms disappear first, and the E. E. G. becomes less individual. In deep sleep it resembles a baby's record, but in lighter sleep there is usually intermittent activity at 14 cycles per second, and this is sometimes prominent just before a subject wakes up from a dream. Hypnosis produces little change unless the subject is of the type who goes into a very deep trance, when the alpha rhythms are said by some to respond to the suggested, rather than the real, conditions.

When the brain is injured, or invaded by a tumor, the affected area tends to develop slow discharges called delta activity (fig. 5). Al-

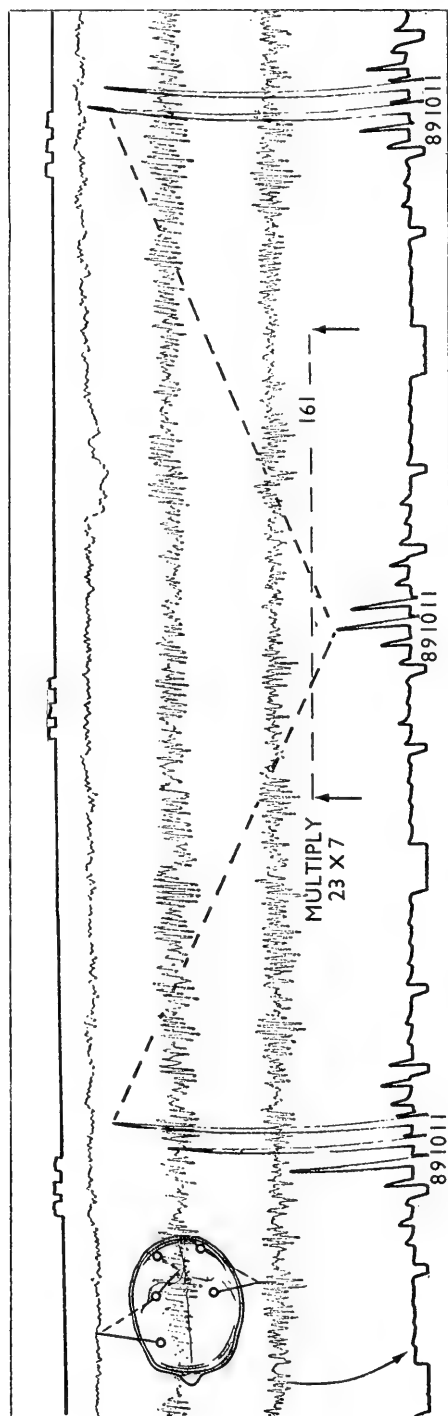


FIGURE 2.—Electroencephalogram from a normal person showing the effect of mental activity while doing a multiplication sum. The alpha activity is reduced and the extent of the reduction is indicated by the smaller size of the peaks at 8, 9, 10, and 11 cycles per second in the analysis.



Demonstration by the author of the effect of rhythmic light stimuli during a meeting in the ether dome of the Massachusetts General Hospital, Boston, in 1946.

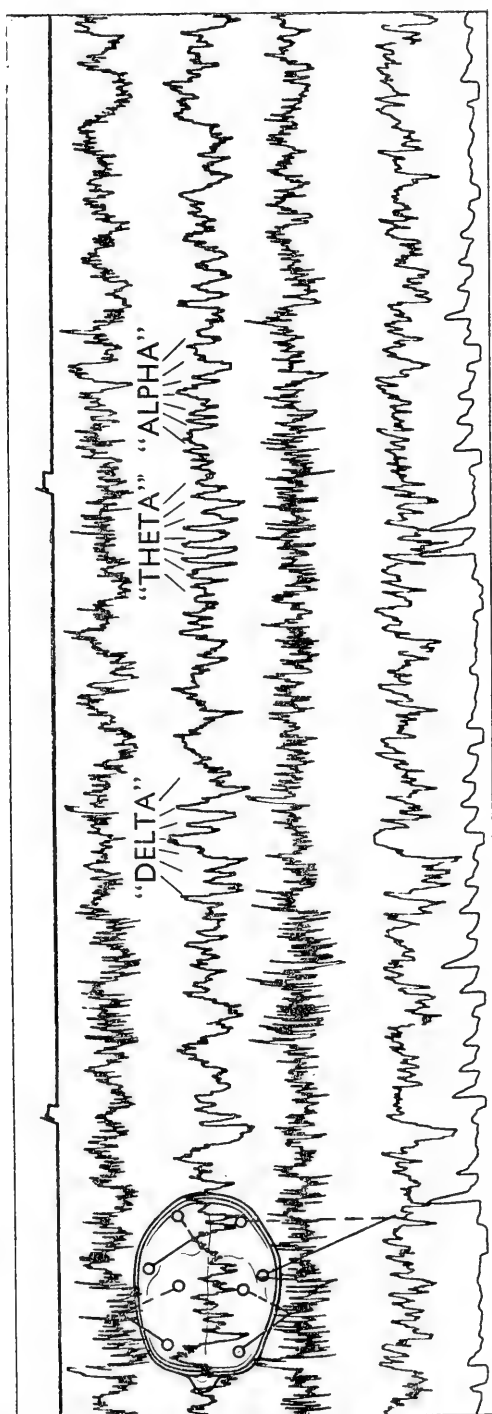


FIGURE 3.—Electroencephalogram from a 1-year-old child showing delta, theta, and alpha components from the posterior region. The analysis is from the frontal areas and demonstrates the absence of consistent rhythmic activity.

though they are usually localized round the lesion, these slow, abnormal delta waves are quite similar to those found in infants and deep sleep, suggesting that they may have some function in assisting the disturbed nervous tissue to rest from its labors, in the same way as pain compels disuse of a broken limb—for the brain can feel no pain, and has little power of healing itself.

The most dramatic variations from the normal are seen in epileptics, particularly during seizures. In petit mal, for example, when the patient suddenly becomes unconscious for a short time, the whole brain generates enormous regular slow waves a hundred times bigger than any normal rhythm, each one with a short spike indenting its crest (fig. 6). One may consider a patient generating these "wave and spike" rhythms, as they are called, as being electrocuted by his own brain.

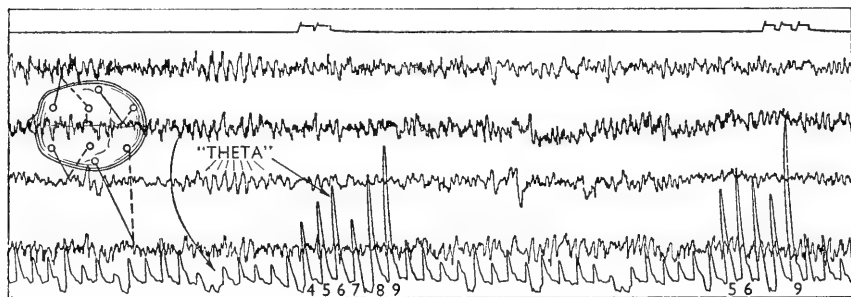


FIGURE 4.—Electroencephalogram from a 3-year-old child showing prominent theta activity combined with alpha. A similar record might be found in an adult with marked aggressive tendencies.

Though always interesting and sometimes useful in the study of organic brain disease and epilepsy, the technique of electroencephalography has been too crude to give much help in problems of mental disorder, or in the investigation of the physiology of behavior. In the last few years, however, the technical resources available to electrophysiologists have been greatly extended by the adoption and adaptation of devices developed during the war for radar or "servo" machinery. Some new instruments, on the other hand, have been specially designed by those working in the field for their own peculiar problems.

The advance has been made on two fronts: first, the development of elaborate and flexible methods of transformation and display of the electrical data; second, the introduction of controlled stimulation of the subject. It will be realized that the ordinary record is really a graph of voltage against time, but since there are inevitably large numbers of cell groups active at the same moment, this graph is nearly always extremely complex and bewildering to the eye, which can pick

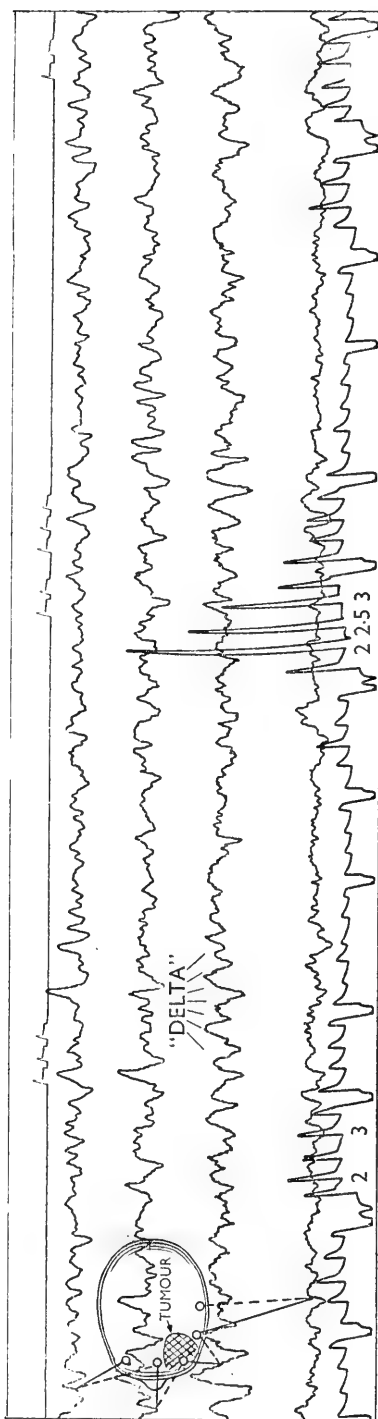


FIGURE 5.—Electroencephalogram from a patient with a large tumor in the left frontal region which is generating the large slow delta waves. Note the peaks at 2, 2.5, and 3 in the analysis from between channels 2 and 3 showing where the slow waves are coming from.

out only one or two of its many components. An instrument has been designed, and is now in use in many laboratories, which automatically breaks down the complex oscillations into their various constituents, rather as a spectroscope resolves white light into its component colors. This wave analyzer writes out on the ordinary record every 10 seconds a frequency histogram corresponding to the Fourier transformation of the primary changes. A mathematician would take several days to perform the same task. Another device, still under development, displays the electrical activity on a battery of 24 cathode-ray tubes, each one corresponding to a small area of the brain. In this "toposcope," voltage is transformed into the brilliance of the cathode-ray screen, and an indication of frequency is given by the way in which the patch of light seems to rotate on each tube.

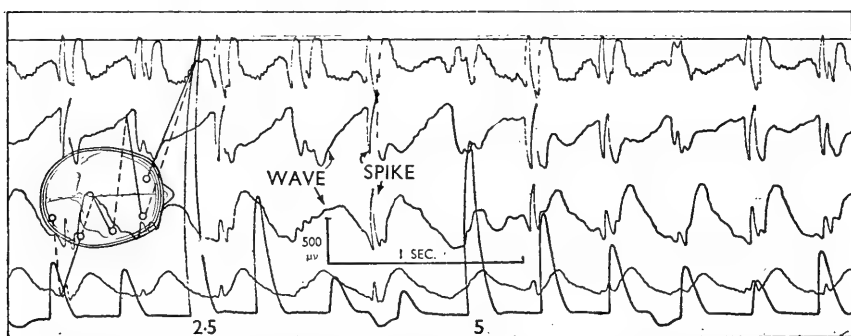


FIGURE 6.—Electroencephalogram taken during a minor epileptic seizure showing the prominent "wave and spike" activity diagnostic of this condition. Note that the time scale is longer than in the other records and that the amplification has been greatly reduced.

Ten years ago these devices would have seemed absurdly elaborate: in another 10 years' time they will probably seem childishly simple compared with the intricacy of brain function as represented by the E. E. G. Even now, we can probably understand less than 1 percent of the total information contained in a record such as those in the figures. We are rather in the position of a visitor from Mars who is deaf and dumb and has no conception of the nature of sound, but is trying to build up a knowledge of languages by looking at the grooves on a phonograph record.

In dealing with a complex signal, there is always the problem of deciding how the significant parts of the message can be made most clear and memorable and the insignificant ones least obtrusive. Success in this discrimination depends upon choosing the right criteria for significance, and this can often be done only empirically until the cipher has been broken, so to speak.

The second sign of progress is that a more active approach is being made to the brain by providing controlled stimuli instead of merely

watching its spontaneous activity. An analogy for this is the development of radar, in which instead of trying to pick up the sound or radiation from an aeroplane, a radio pulse is transmitted toward it and the echoes produced are observed in relation to the original signal. In the study of the brain the transmitted signals are called stimuli and the echoes responses, but the resemblance in both method and results is very close. The sound from an aeroplane travels too slowly to indicate the position of the source, and any radio signals it emits may be deliberately or inadvertently confusing to the observer, but an aircraft cannot avoid reflecting the radar pulse. In the brain, the spontaneous actions or thoughts which it initiates may be delayed, by a variable time, after the first electrical sign of their occurrence, and the spontaneous activity is usually too varied and uncontrollable to correlate with other physiological variables, but the central nervous system cannot escape the influence of external stimuli, since to respond to them is one of its prime functions. Moreover the stimuli can be given at moments controllable by the observer and at known frequencies.

By using techniques precisely similar to those developed for radar, the response to a regular stimulus can be displayed on a cathode-ray oscilloscope, so that scores of successive responses are precisely superimposed—whereas the random or spontaneous activity is blurred and unobtrusive. This method has been turned to great account by Dawson [1]² in the study of the electrical responses to stimulation of sensory nerves in the limbs. Results of considerable general interest have been obtained by using rhythmic flashes of light for investigating the response characteristics of the visual cortex [2], [3], [4]. When rhythmic stimulation of this sort is used, the frequency analyzer already mentioned is of great value, since the regular responses at the stimulus frequency can be traced through the brain, even when they are smaller than the irregular background oscillations, because their steady recurrence is seen by the analyzer as a prominent peak of activity at a single frequency.

This method has proved powerful in clinical applications, particularly when the resting records present no diagnostic features. In some epileptics, for example, it is possible to find a flash frequency which sets up in the brain electrical activity which combines with the oscillations already present to produce a diagnostically abnormal pattern, and a clinical seizure. This observation, in combination with the known features of the spectrum of epileptic records, has suggested the hypothesis that the condition known as idiopathic epilepsy is due to the occasional synchronization by sensory or motor impulses of otherwise unrelated electrical rhythms. In cases with organic disease of the brain the response to rhythmic flashes of light is often

² Numbers in brackets refer to authorities cited at end of article.

disturbed near the site of a lesion, even when the resting activity appears normal.

In normal subjects, bright rhythmic flashes of light have been found to evoke peculiar sensations at certain frequencies. All subjects describe checkered, whirling patterns of light and shade when the stimulus frequency is between 7 and 30 flashes per second, and most see brilliant and ever-changing colors with white light. Some people, again, describe vivid hallucinations and dreamlike experiences of flying or of distortion of the time sense. Most interestingly, whenever a peculiar sensation is experienced, some part of the brain displays at the same time an unusual and exaggerated degree of electrical activity at the frequency of the stimulus or a multiple of it. Furthermore, when, during an episode of this sort, the subject is encouraged to submit to the sensation and to reinforce it with memories of a similar type, both the sensation and its associated electrical discharge are augmented. Conversely, when the subject is distracted by another stimulus or, by an effort of will, refuses to accept the vision or state of mind induced by the stimulus, both the subjective and electrical phenomena subside.

In some of the most striking examples of this effect, vivid and emotionally powerful feelings have been correlated with electrical responses in the temporal and frontal lobes, not at the stimulus frequency itself, but at harmonics of it. In general terms, complex individual mental disturbances can be set up by an apparently neutral physiological stimulus when this is rhythmic and powerful enough, and these mental states are strictly correlated with electrical events in parts of the brain which have nothing to do with the reception of visual stimuli.

It will be recalled that unhappy children and bad-tempered adults often show discharges at about 6 cycles per second in the temporal lobes. It is at least very suggestive that when similar electrical discharges are evoked in normal people by rhythmic stimulation, a feeling of emotional discomfort and irritability appears. It would seem logical to adopt, as a working hypothesis, the notion that certain temperaments and states of mind are associated with electrical activity at a particular frequency in certain nervous circuits within the brain, and one can foresee a new meaning of the word "temper" as a strictly scientific term to describe the tuning and resonance of these circuits. In the testing of working hypotheses "the road of excess leads to the palace of wisdom," and it may be necessary to develop a complete theory of the relation between brain and mind in these electrical terms before the appearance of absurd conclusions or predictions signals the inadequacy of our ideas. Even at the present time the introduction of electrical terms and analogies has accelerated advance, for it is now possible to use the methods of electrical engineers in the

study of brain physiology. For example, when an engineer observes a sustained electrical oscillation he looks for what he calls "positive feedback" and it seems likely that, in the brain, feedback circuits actually exist, and that their properties can be studied exactly as if the living organ were a complex transmission system. Going a step further, it has been found possible to construct models using devices similar to those postulated in the brain, and these models behave in a very lifelike fashion, particularly when positive and negative feedback circuits are combined. The positive feedbacks provide mechanisms for hunting, scanning, and testing the model's environment for stimuli and information, and the negative feedbacks or reflexes ensure that any action the model may decide to take will be as near as possible to that necessary for stability and survival. It is surprising how complex and apparently unpredictable the behavior of one of these models can be when it is placed in the irregular environment of an ordinary room, even when it contains only half a dozen units as compared with the millions in the human brain.

The great fertility of the marriage between brain physiology and engineering has suggested to many people that the family of subjects thus united is worthy of a special name, and Wiener [5] has proposed "cybernetics," from the Greek word meaning "steersmanship," since the fundamental common problem seems to be the way in which complex dynamic systems direct themselves toward various goals. It has been predicted that when properly established this new branch of science may have as great an effect upon our life and surroundings as the achievements of nuclear physicists.

A comparison has already been made with the great calculating machines, but these are of course enormously more specialized than any viable living organism, since their sole function is to perform certain types of calculation at immense speed. In contrast to this, the brain performs innumerable functions, though none with very great accuracy or velocity—but it can design the machines. A good-quality human brain has more possibilities than any other known structure in the universe, and we should not be far wrong in calling it "the universal machine."

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ENERGY FROM FOSSIL FUELS¹

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Shell Oil Co., Inc.

INTRODUCTION

It is difficult for those of us living today, especially in the more industrialized areas of the world, to appreciate fully the uniqueness of the events that we are witnessing. During our lifetime, and in the immediately preceding century whose history is most familiar to us, we have witnessed continuous change—usually continuous increase. We have seen a few European immigrants to North America expand during a few centuries into a population of over 170 millions. We have seen villages grow into large cities. We have seen an area of primeval forests and prairies transformed into widespread agricultural developments. We have seen a transition from a handicraft and agrarian culture to one of complex industrialization. In only a few generations we have witnessed the transition from human and animal power to electrical power supernetworks; from the horse and buggy to the airplane.

At the same time our senses have been dulled by the platitude that history repeats itself. As a consequence, we have become so inured to change, especially to growth and to increase, that it is difficult for us not to regard the rates of change which we are now witnessing as the normal order of things.

In order to appraise more accurately our present position and the limitations which may be imposed upon our future, it is well that we consider in historical perspective certain fundamental relationships that underlie all our activities. Of these the most general are the properties of matter and those of energy.

From such a point of view the earth may be regarded as a material system whose gain or loss of matter over the period of our interest is negligible. Into and out of this system, however, there is a continuous flux of energy, in consequence of which the material constituents of the surface of the earth undergo continuous or intermittent

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circulation. These material constituents comprise the familiar chemical elements, only a few of which, occurring in quantities of but a few parts per million, are significantly radioactive.

For the present discussion we shall restrict our attention to the non-radioactive materials and shall summarily state that the events of our interest are the result of a flux and degradation of a supply of energy, and the corresponding circulation of matter regarded as consisting of nontransmutable and indestructible chemical elements.

All but a minute part of the energy involved in this process is that derived from solar radiation, and a small fraction of the matter at or near the surface of the earth occurs in the peculiar aggregates known as living organisms. A part of the solar radiation incident upon the earth serves to propel a circulation of matter into and out of this organic assemblage. In this process an amount of energy roughly proportional to the mass of the matter incorporated in organisms is held in storage as chemical potential energy.

From geological evidence, organisms have existed upon the earth for probably as long as a billion years, during the last 500 million of which a fraction of these organisms has become buried in the accumulations of sediments under conditions which have prevented complete disintegration and complete loss of their energy content. Consequently, there exist in the sedimentary rocks of the earth today accumulations of the remains of fossil organisms in the form of coal, oil shale, and petroleum and natural gas, which are rich in fossil energy stored up from the sunshine of the past 500 million years. This process of accumulation is doubtless still occurring, but the rate is probably not very different from that of the past, so that, for an order of magnitude, the accumulation during the next million years will probably not exceed one five-hundredth of the accumulation which has occurred already.

RISE OF HUMAN SPECIES

With this background let us now consider the development of the human species. From archeological and geological evidence it appears that a species recognizable as *man* must have existed roughly a million years ago. The population of this species at that stage is unknown but evidently was not large. It existed in some sort of ecological adjustment with the rest of the organic complex, and competed with the other members of the complex for a share of solar energy essential to its existence. At that hypothetical stage its sole capacity for the utilization of energy consisted in the food it was able to eat—about 2,000 kilogram-calories per capita per day.

Between that stage and the dawn of recorded history, this species is distinguished from all others in its inventiveness of means for the

conquest of a larger and larger fraction of the available energy. The invention of clothing, the use of weapons, the control of fire, the domestication of animals and plants, and many other similar developments all had this in common: They increased the fraction of solar energy available to the use of the human species, and they continuously upset the ecologic balance in favor of an increase in numbers of the human species, with corresponding adjustments in all the other populations of the complex of which the human species was a member.

From that early beginning until the present day this progression has continued at an accelerated rate. It has involved the development of wind power and water power, the smelting of metals with wood as fuel, the extensive employment of beasts of burden. However, throughout this period until within the last few centuries the *rate* of these changes has been small enough for population growth to keep pace. The energy consumed per capita, therefore, has increased but slightly.

ENERGY FROM FOSSIL FUELS

Emancipation from this dependence upon contemporary solar energy was not possible until some other and hitherto unknown source of energy should become available. This had its beginning about the thirteenth century when some of the inhabitants of Britain made the discovery that certain black rocks found along the shore of the east coast, and thereafter known as "sea coles," would burn. From this discovery there followed in almost inevitable succession the mining of coal and its use for the smelting of metals, the development of the steam engine, the locomotive, the steamship, and steam-electric power.

This development was further augmented when, about a century ago, the second large source of fossil energy—petroleum and natural gas—was tapped, leading to the internal-combustion engine, the automobile, the airplane, and Diesel-electric power.

A third source of fossil energy, oil shale, although exploited on a small scale for almost a century, is only now approaching its phase of rapid development.

RATES OF PRODUCTION

It is to the rate of increase and the magnitude of the consumption of the energy from fossil fuels that I now wish to direct your attention.

Consider coal. Although production statistics for the earlier periods are not available, it is known that from the initial discovery and use of "sea coles" to the present there has been a continuous increase in the rate of consumption of this commodity. During the eighteenth century the need for power for the coal mines led to the development of the steam engine, and the demand for better means of transportation led first to the railroad and then to the steam locomotive. We

know also that before the end of the eighteenth century the employment of this new source of energy had reached such magnitude as to produce the major social and economic disturbances in Britain referred to as the "Industrial Revolution."

By 1864 (1, 2),² from which date annual world-production statistics are available, the production of coal in the world (fig. 1) had

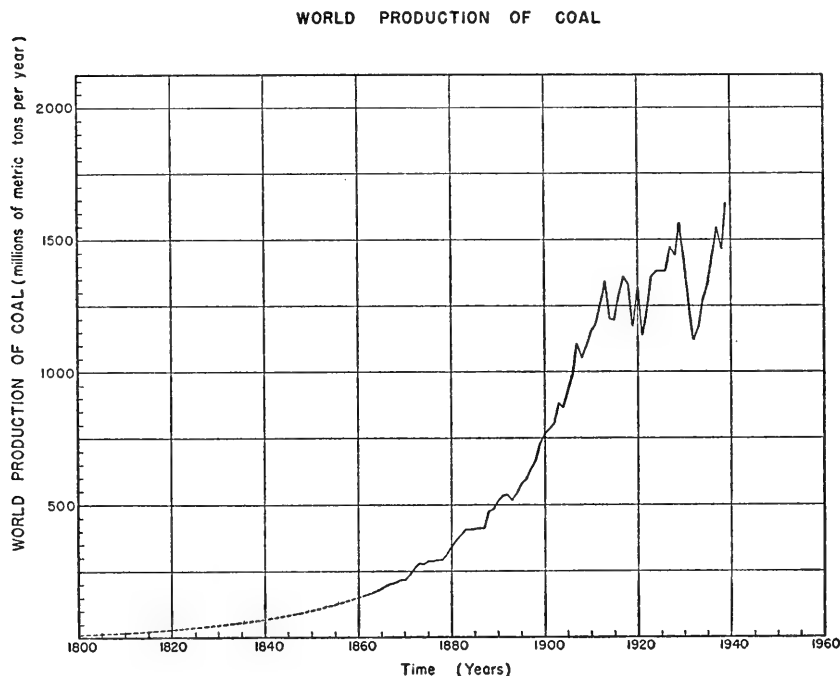


FIGURE 1.

reached about 180 million metric tons a year, and from that date until 1914, when it had reached a rate of 1,300 million tons a year, it continued to increase geometrically at a rate of 4 percent a year, or at a rate such that the annual production was doubling every 17 years.

The length of time during which coal has been mined is likely to be misleading. To appreciate the magnitude of what is happening and the brevity of time during which most of it has occurred, consider these facts: By the end of 1947 the cumulative production of coal during all past human history amounted to approximately 81 billion metric tons. Of this, 40 billions, or approximately one-half, have been mined and consumed since 1920. Sixty-two billions, or more than three-quarters, have been produced since 1900—during our lifetime.

² Numbers in parentheses refer to bibliography at the end of the paper

The world production of petroleum is shown graphically in figure 2 (3). The first commercial production of petroleum was begun in 1857 in Rumania. Two years later the first oil well in the United States was completed. From these beginnings, with only an occasional setback, the world production of petroleum has increased spectacularly, reaching, by the end of 1947, an annual rate of 477

WORLD PRODUCTION OF PETROLEUM

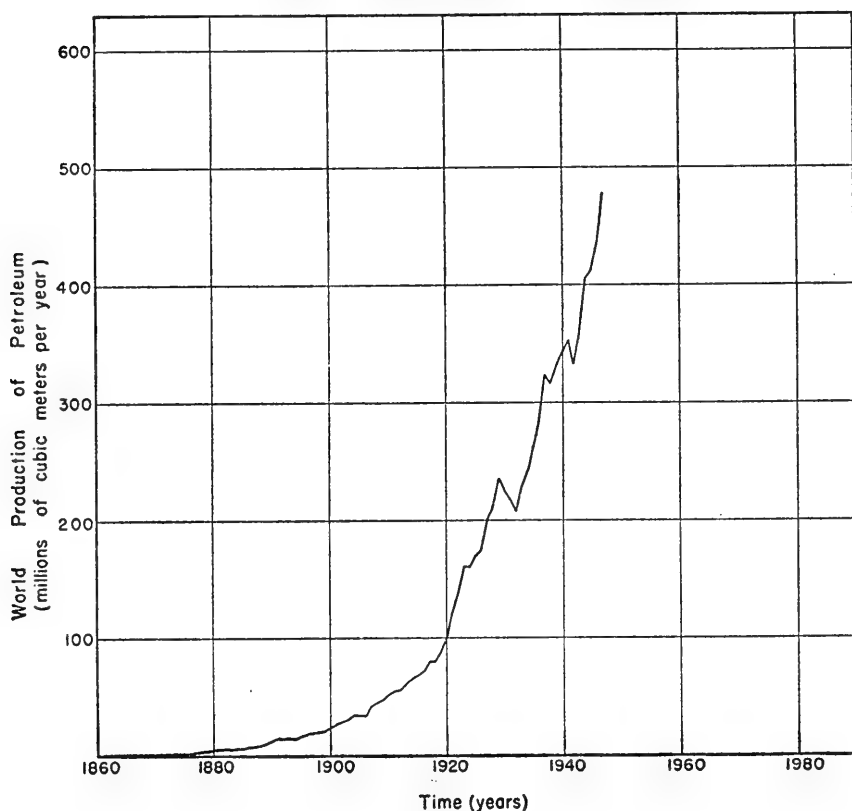


FIGURE 2.

million cubic meters (3 billion United States barrels). From 1860 to 1929 the rate of production doubled, on the average, every $7\frac{1}{2}$ years, or at an average annual rate of increase of slightly more than 9 percent. Since 1929 the rate of increase has declined somewhat and the doubling period increased to about 15 years.

Again, to appreciate the brevity of time during which most of this has occurred, the cumulative production by the end of 1947 was 9.17 billion cubic meters (57.7 billion United States barrels). Of this, one-half has been produced and consumed since 1937, and 97 percent since 1900.

The energy content of the coal and petroleum that have been consumed, expressed in kilogram-calories, is shown in figure 3. From these two sources the energy amounted to 15×10^{15} or 15 thousand trillion kilogram-calories per year in 1939. Approximately four-fifths of this amount was contributed by coal, and one-fifth by petroleum.

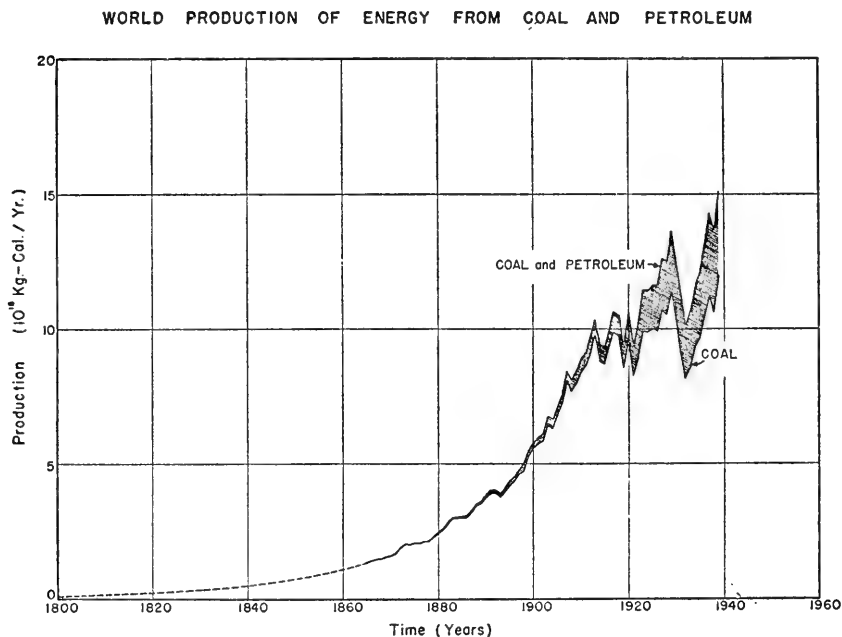


FIGURE 3.

Because of the lack of world-production statistics the energy from natural gas has not been included. In the United States about 400 cubic meters of natural gas are produced for each cubic meter of oil, with an energy content of about 0.4 of that of oil. Since oil and gas are genetically related it may be presumed that this approximate ratio is valid for the rest of the world also. Hence, the energy from the natural gas that has been produced may be assumed to be at least 40 percent of that of petroleum.

GROWTH OF POPULATION

In the introductory remarks it was intimated that one of the most disturbing ecological influences of recent millennia had been the human species' proclivity for the capture of energy, resulting in a progressive increase of the human population (4, 5). This is borne out by the growth curve of human population since 1650, shown in figure 4, based on the studies of Carr-Saunders (6), and the recent

estimate of Davis (7). According to these estimates the world population has increased from about 545 millions in 1650 to 2,171 millions by 1940. The greatest rate of increase during this period has been that of the last half century during which the world population has been increasing at such a rate as to double itself once a century, or at an annual rate of increase of 0.7 percent.

GROWTH OF WORLD POPULATION

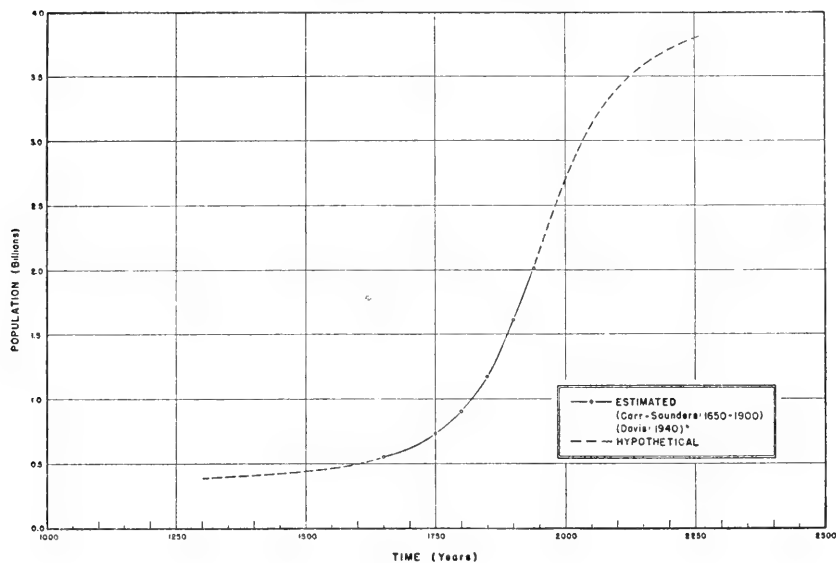


FIGURE 4.

That such a rate is not "normal" can be seen by backward extrapolation. If it had prevailed throughout human history, beginning with the Biblical Adam and Eve, only 3,300 years would have been required to reach the present population. If, on the contrary, we assume that the human race has been in existence for a million years, and has increased at a uniform exponential or geometrical rate, starting with a single pair, the present population would be reached in that time by a rate of increase of 2.1×10^{-4} percent per year, or a rate of growth that would require 33,000 years for the population to double. At such a rate it is doubtful whether any census could detect a change in the population during one man's lifetime.

That the present rate of growth cannot long continue is also evident when it is considered that at this rate only 200 more years would be required to reach a population of nearly 9 billion—about the maximum number of people the earth can support. In fact, at such a rate, only 1,600 years would be required to reach a population density of one person for each square meter of the land surface of the earth.

ENERGY PER CAPITA

Prior to 1800 most of the energy available to man was that derivable from his food, the labor of his animals, and the wood he used for fuel. On a world-wide basis it is doubtful if the sum of these exceeded 10,000 kilogram-calories per man per day, and this was a several-fold increase over the energy from food alone.

After 1800 there was superposed on these sources the energy from fossil fuels. From a world average of 300 kilogram-calories per capita per day in 1800 the energy from coal and petroleum increased to 9,880 by 1900, and to 22,100 by 1940. In the areas of high industrialization this quantity is much larger. In the United States, for example, the energy from coal and petroleum consumed per day per capita amounted in 1940 to 114,000 kilogram-calories (2), and from coal, petroleum, and natural gas 129,000.

PHYSICAL LIMITS TO EXPANSION

From the foregoing data it should be clear that while we are concerned with a progression of ancient origin, the developments within the last century, and especially within the last few decades, are decidedly exceptional. One cannot refrain from asking, "How long can we keep it up? Where is it taking us?"

This leads us to consider what physical limitations there may be upon the quantity of various types whose expansion we have noted. In the case of the fossil fuels the answer is simple. As remarked before, these fuels represent an accumulation over 500 million years of geologic time, and any additional accumulation that may be expected within the next 10,000 years is negligible. When these fuels are burned, their material content remains upon the earth in a relatively useless form, but the precious energy, after undergoing a sequence of degradations, finally leaves the earth as spent, long-wavelength, low-temperature radiation. Hence, we deal with an essentially fixed storehouse of energy, which we are drawing upon at a phenomenal rate. The amount that remains at any given time equals the amount initially present less that which has been consumed already.

The amount consumed up to any given time is proportional to the area under the curve of annual production plotted against time. This area may approach but can never quite equal the amount initially present. Thus we may announce with certainty that the production curve of any given species of fossil fuel will rise, pass through one or several maxima, and then decline asymptotically to zero. Hence, while there is an infinity of different shapes that such a curve may have, they all have this in common: that the area under each must be equal to or less than the amount initially present.

AMOUNTS OF FOSSIL FUELS

Although the quantities of fuels upon the earth are not known precisely, their order of magnitude is pretty definitely circumscribed. The most accurately known is coal. At the Twelfth International Geological Congress at Ottawa in 1913 a world review of coal was made and the amount capable of being mined was estimated to be about 8×10^{12} metric tons. Since that time some adjustments in the estimates have been made, giving us a present figure of about 6.3×10^{12} metric tons of coal initially present.

Within the past few years this figure has been criticized by mining engineers (8, 9) on the grounds that while the estimated amount of coal may in fact be present, the amount recoverable by practical mining operations is but a fraction—possibly as small as one-tenth—of the foregoing estimate. The degree of validity of this criticism still remains to be determined.

For petroleum the accuracy of estimation is considerably less than for coal but still is probably reliable as to the order of magnitude. The method of estimation in this case is that of sampling. In the better-known areas the amount of petroleum produced per unit volume of certain classes of rocks has been determined. The areas and volumes (within drillable depths) of similar rocks over the earth are fairly well known. By application of the same factor for the undrilled areas as for those now well known, an order of magnitude of the petroleum that may exist may be obtained.

The most comprehensive of such studies that have so far been made public appear to be those of Weeks, which are cited by Wallace E. Pratt (10, 11, 12). According to these studies, in a volume of $10\text{--}12.5 \times 10^6$ kilometers³ ($2.5\text{--}3.0 \times 10^6$ miles³) of sediments in the United States there have already been discovered 8.4×10^9 cubic meters (53×10^9 barrels) of oil. This represents about 10 percent of the total volume of such sediments of the land areas throughout the world. Hence, it is estimated that for the world there should have been present initially the order of 10 times as much oil as for the United States. A similar volume of sediments occurs on the continental shelves which may contain a volume of oil about equal to that of the land sediments.

Assuming that the land areas of the United States will produce 16×10^9 cubic meters (100 billion barrels), then a reasonable estimate for the world would be:

Land	$160 \times 10^9 \text{ m.}^3$
Continental shelves	$160 \times 10^9 \text{ m.}^3$
Total	$320 \times 10^9 \text{ m.}^3$

These figures are regarded as being somewhat liberal and the quantity of oil may actually be considerably less.³

In addition to the above, the Athabaska Tar Sands (10) are estimated to contain about 30×10^9 cubic meters of oil.

The amount of natural gas may be estimated at 400 cubic meters of gas per 1 of oil, or at an energy content of 40 percent that of oil.

The oil shales of the world are less well known. Those of the United States, especially the Green River shales, are estimated to contain at least 55×10^9 cubic meters of oil. Assuming that the rest of the world has about three times as much oil shale as the United States, we would obtain, for an order of magnitude, 160×10^9 cubic meters (1,000 billion barrels) of oil from this source.

TOTAL ENERGY OF FOSSIL FUELS

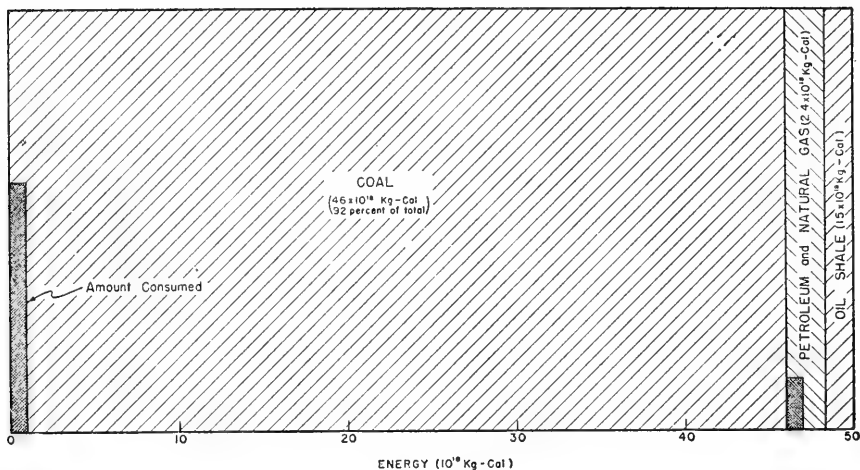


FIGURE 5.

The results of these estimates are given in table 1 and shown graphically in figure 5. It will be noted in particular that 92 percent of

³ Since the foregoing was first published the author has obtained directly from Dr. L. G. Weeks his own estimate of the total world supply of petroleum, which is more conservative than the figures cited above. For the land areas Dr. Weeks estimates an amount of about 600 billion barrels (96×10^9 m.³), and for the continental shelves about 400 billion barrels (64×10^9 m.³), giving a total of 1,000 billion barrels, or 160×10^9 m.³, which is just half the figure employed above.

These figures were also given in a written discussion, by Dr. Weeks, of a paper by Prof. A. I. Levorsen on "Estimates of Undiscovered Petroleum Reserves" read before the United Nations Scientific Conference on the Conservation and Utilization of Resources at Lake Success, August 22, 1949. (See Weeks, L. G., Highlights on 1947 developments in foreign petroleum fields, Bull. Amer. Assoc. Petrol. Geol., vol. 32, No. 6, p. 1094, June 1948; Levorsen, A. I., Estimates of undiscovered petroleum reserves, Proc. U. N. Scientific Conference on the Conservation and Utilization of Resources, vol. 1, Plenary Meetings, pp. 94-99, and discussions, pp. 103-104, by M. King Hubbard, and pp. 107-110, by L. G. Weeks, 1950.)

TABLE 1.—*Energy of fossil fuels*

Resource	Initially present		Percentage total initial energy	Already consumed		Percent initial
	Quantity	Energy content 10 ¹⁸ kilo-gram-calories		Quantity	Energy content 10 ¹⁸ kilo-gram-calories	
Coal ^a -----	6.3 x 10 ¹² metric tons	46.0	92.2	81 x 10 ⁹ metric tons	0.59	1.3
Petroleum ^b -----	160 x 10 ⁹ m ³ -----	1.5	3.0	9.17 x 10 ⁹ m ³ -----	.087	5.7
Tar sands ^c -----	30 x 10 ⁹ m ³ -----	.3	.6	-----	-----	-----
Natural gas ^d -----	64 x 10 ¹² m ³ -----	.6	1.2	3.7 x 10 ¹² m ³ -----	.035	5.7
Oil shale ^e -----	160 x 10 ⁹ m ³ -----	1.5	3.0	-----	-----	-----
Total-----	-----	49.9	100.0	-----	.712	1.43

^a Revised from estimate Twelfth International Geological Congress (1913).^b Based on estimate of Wallace E. Pratt, Petroleum on continental shelves, Bull. Amer. Assoc. Petrol. Geol. vol. 31, pp. 657-672, 1947.^c Pratt, Wallace E. Oil in the earth, Univ. of Kansas Press, p. 44, 1942.^d Based on gas/oil ratio of 400 m³/m³, or energy of gas = 0.4 energy of oil.^e Belser, Carl, Oil shale resources of Colorado, Utah, and Wyoming, Amer. Inst. Min. Eng. Techn. Publ. No. 2358, May 1948.

the estimated total is represented by coal—a figure that will not be greatly altered by any reasonable adjustments of the estimates of the remaining fuels, but may be considerably altered if the minable amount of coal is less than usually assumed.

The amount of the initial coal already consumed is 1.35 percent; that of oil and natural gas, inclusive of the Athabaska Tar Sands, about 5 percent. The fraction of shale oil already produced is negligible. From these data the estimated initial supply of energy stored in fossil fuels is of the order of 50×10^{18} kilogram-calories, of which 0.7×10^{18} , or 1.5 percent, has already been consumed.

RATE OF CONSUMPTION CURVES FOR FOSSIL FUELS

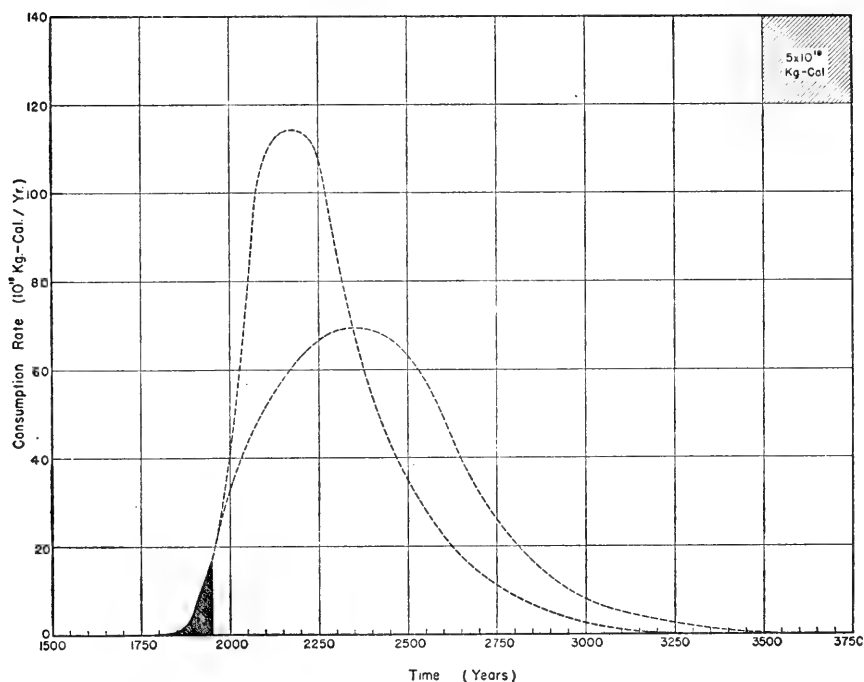


FIGURE 6.

FUTURE OF FOSSIL ENERGY CONSUMPTION

With this information we are prepared to consider what the future of the consumption of fossil energy may be. In figure 6 is shown the production of fossil energy up to the present, and two possible projections into the future. One production curve rises to a high peak and descends steeply; the second rises more slowly to a lower maximum and descends gently. The area under each curve, however, is approximately the same, namely 10 unit squares, each of which represents 5×10^{18} kilogram-calories.

If, as the coal-mining engineers intimate, the amount of coal is much less than herein assumed, so much smaller will be the area under the curve and so much sooner the approach to exhaustion. How soon the decline may set in, it is not possible to say. Nevertheless, the higher the peak to which the production curve rises, the sooner and the sharper will be the decline.

WATER POWER

The exploitation of water power, like that of coal, is of fairly ancient origin, but also, like coal, until the last half century its utilization has been small. Unlike fossil fuels, however, water power represents a fraction of current solar energy, which changes but slowly with time and is being continuously degraded into waste heat irrespective of whether it is utilized or not.

A growth curve of the utilization of water power, therefore, should rise in a manner similar to those of the fossil fuels, but instead of then declining to zero it should level off asymptotically to a maximum as all available water power is brought into utilization. At least this is physically possible.

In view of the eventual exhaustion of fossil fuels, it is of interest to know to what extent water power can be depended upon to replace them. In table 2 are listed the installed water-power capacities of the various continents for the year 1947 and estimates of their total potential capacities (13). In addition, the number of kilowatt-hours of energy that such capacity should produce per year, and, finally, the energy, expressed in heat units, of the amount of fuel that would be required to produce an equivalent amount of power, is given.

In these calculations the potential installed capacity is taken to be equal approximately to the power at mean rate of flow and 100 percent efficiency. The estimated output is based on a load factor of 0.5, and the fuel equivalent of the power produced is based upon a thermodynamic efficiency of steam plants of 20 percent—figures which characterize installations in the United States at the present time.

The present and potential water-power situation for the world is summarized graphically in figure 7. The potential capacity is about 1,500 million kilowatts of which present installations amount only to 65 millions, or 4.3 percent.

The energy content of the equivalent fuel that would be required to produce the potential water-power output is about 28×10^{15} kilogram-calories per year, or one and a half times the present rate of consumption of energy from fossil fuels.

Hence, with maximum utilization, it would be possible with water power to supply to the earth an amount of energy comparable with that currently obtained from the use of fossil fuels.

TABLE 2.—*Developed and potential water power of the world, 1947*

Continent	Installed capacity ^a		Total potential water power				Potential output per year ^c	
	10 ⁶ horse-power	10 ⁶ kilo-watts	Ordinary minimum flow ^a		Mean flow ^b		10 ⁶ kilowatt-hours	Energy of equivalent fuel ^d 10 ¹² kilo-gram-calories
			10 ⁶ horse-power	10 ⁶ kilo-watts	10 ⁶ horse-power	10 ⁶ kilo-watts		
Africa-----	0. 368	0. 274	274	204	823	612	2. 69	11. 6
Asia-----	12. 059	8. 98	151	113	453	339	1. 49	6. 42
Europe-----	34. 937	26. 0	68	51	204	153	. 672	2. 89
North America-----	35. 849	26. 7	84	63	252	189	. 824	3. 54
Oceania-----	1. 284	0. 955	20	15	60	45	. 197	. 85
South America-----	2. 392	1. 79	67	50	201	150	. 658	2. 83
Total-----	86. 900	64. 8	664	496	1, 992	1, 488	6. 53	28. 13

^a U. S. Geological Survey, Developed and potential water power of the world, 1948.^b Computed on basis: Average mean flow — minimum flow —=3.^c Based on load factor of 0.5.^d Computed on basis of efficiency of 20 percent for steam plants, or 4,300 kilogram-calories per kilowatt-hours.

TIME PERSPECTIVE

The present state of human affairs can best be appreciated in the light of a time perspective, minus and plus, of some tens of thousands of years from the present, as depicted in figure 8. On such a time scale the phenomena we have discussed are represented by abrupt, nearly vertical rises from zero or near zero to maximum values. The consumption of energy from fossil fuels is thus seen to be but a "pip," rising sharply from zero to a maximum, and almost as sharply declining, and thus representing but a moment in the total of human history.

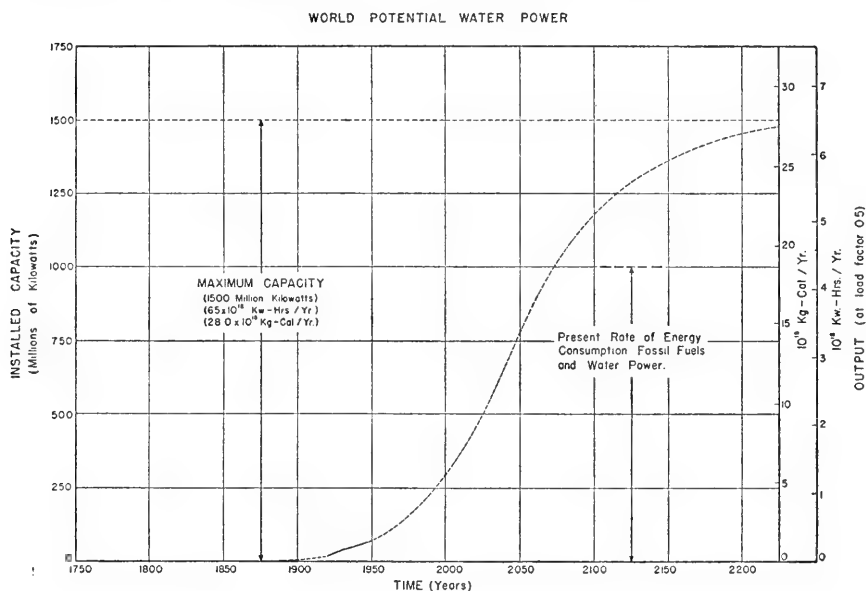


FIGURE 7.

The energy from water power and solar radiation also rises almost vertically. It is physically capable of leveling off asymptotically to a maximum value as shown in curve I and being held there more or less indefinitely. However, it is also possible that it may decline to some lower intermediate value as shown by curve II, or to zero, as in curve III, depending upon the state of human culture during the next few thousand years.

Likewise the consumption of energy per capita, after having risen very gradually from 2,000 to possibly 10,000 kilogram-calories per day, is seen to increase suddenly to a maximum value of several times the highest previous value. Again it is physically possible to maintain a high value, as indicated by curve I, on a stable basis for an indefinite period of time from current energy sources, particularly direct and indirect solar radiation. It also is possible, however, that through

cultural degeneration this curve may decline, as in curve II, to the subsistence level of our agrarian ancestors.

Viewed on such a time scale, the curve of human population would be flat and only slightly above zero for all preceding human history, and then it, too, would be seen to rise abruptly and almost vertically to a maximum value of several billion. Thereafter, depending largely upon what energy supplies are available, it might stabilize at a maximum value, as in curve I, or more probably to a lower and more nearly optimum value, as in curve II. However, should cultural degeneration occur so that the available energy resources should not be utilized, the human population would undoubtedly be reduced to a number appropriate to an agrarian existence, as in curve III.

HUMAN AFFAIRS IN TIME PERSPECTIVE

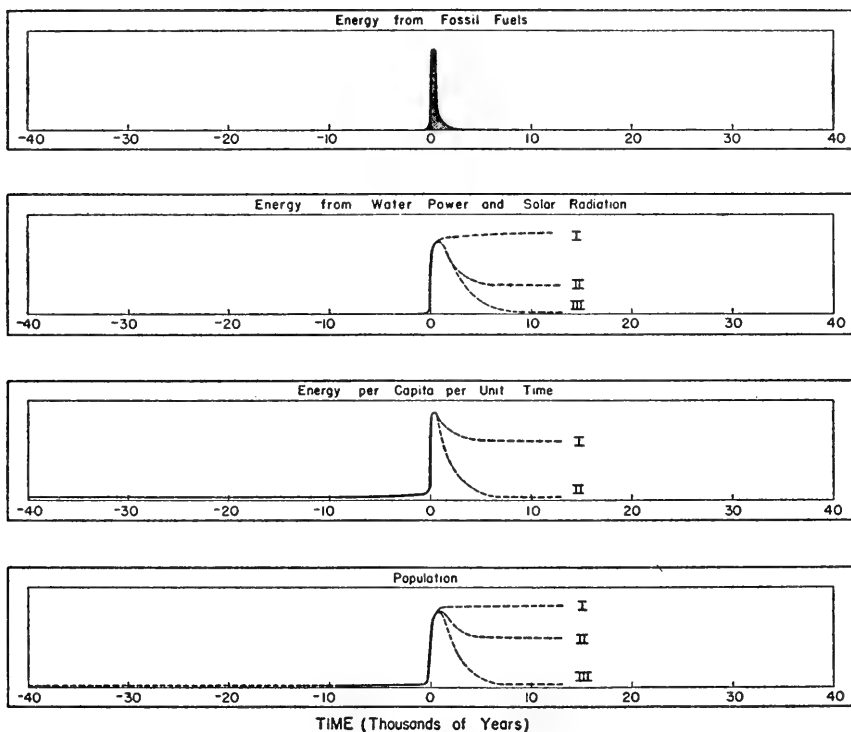


FIGURE 8.

These sharp breaks in all the foregoing curves can be ascribed quite definitely, directly or indirectly, to the tapping of the large supplies of energy stored up in the fossil fuels. The release of this energy is a unidirectional and irreversible process. It can only happen once, and the historical events associated with this release are necessarily without precedent, and are intrinsically incapable of repetition.

It is clear, therefore, that our present position on the nearly vertical front slopes of these curves is a precarious one and that the events we are witnessing and experiencing, far from being "normal," are among the most abnormal and anomalous in the history of the world. Yet we cannot turn back; neither can we consolidate our gains and remain where we are. In fact, we have no choice but to proceed into a future that we may be assured will differ markedly from anything we have experienced thus far.

Among the inevitable characteristics of this future will be the progressive exhaustion of the mineral fuels and the accompanying transfer of the material elements of the earth from naturally occurring deposits of high concentration to states of low-concentration dissemination. Yet despite this, it will still be a physical possibility to stabilize the human population at some reasonable figure and by means of the energy from sunshine alone to utilize low-grade concentrations of materials and still maintain a high-energy industrial civilization indefinitely.

Whether this possibility will be realized or whether we shall continue as at present until a succession of crises—overpopulation, exhaustion of resources, and eventual decline—develops depends largely upon whether a serious cultural lag can be overcome. In view of the rapidity with which the transition to our present state has occurred it is not surprising that such a cultural lag should exist and that we should continue to react to the fundamentally simple physical, chemical, and biological needs of our social complex with the sacred-cow behavior patterns of our agrarian and prescientific past. However, it is upon our ability to eliminate this lag and to evolve a culture more nearly in conformity with the limitations imposed upon us by the basic properties of matter and energy that the future of our civilization largely depends.

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PERMAFROST¹

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[With 12 plates]

Permafrost (perennially frozen ground) is a widespread geologic phenomenon whose importance and ramifications are rapidly becoming better known and more clearly understood. For many decades European scientists have been describing surficial features produced by frost action and permafrost, but for the most part they have given only passing reference to the perennially frozen ground. The current problem is to understand permafrost in order to evaluate it in the light of any particular endeavor, whether practical or academic. To understand permafrost we need a precise, standardized terminology, a comprehensive classification of forms, a systemization of available data, and coordination of effort by geologists, engineers, physicists, botanists, climatologists, and other scientists in broad research programs. These objectives are only gradually being realized.

This paper is largely a compilation of or reference to recent available literature. Its purpose is to make information more generally available concerning some of the many ramifications and practical applications of permafrost. New data from unpublished manuscripts in the files of the United States Geological Survey also are included where appropriate for clarity or completeness. Inna V. Poiré, of the United States Geological Survey, has prepared numerous condensations of Russian papers on permafrost and made them available to the author. Others were made available through the National Military Establishment. The library of the Engineers School, the Engineer Center, Fort Belvoir, Va., has many abstracts, condensations, and translations of Russian works that are available to civilian readers. References in this paper generally are only to the later American or German works, as most contain accounts of the earlier literature. The bulk of the literature, unfortunately, is in Russian and unavailable to the average reader, but some of it has been summarized by Muller (1945). A list of 190 titles of Russian articles dealing with permafrost is given by Weinberg (1940). The Arctic Insti-

¹ Published by permission of the Director, U. S. Geological Survey. Reprinted by permission from Trask's *Applied Sedimentation*, published by John Wiley & Sons, Inc., 1950. Minor modifications have been made, and some new references have been added by the author, but no attempt has been made to revise the paper completely or to list all new permafrost papers.

tute of North America (Tremayne, 1948) is currently preparing an annotated bibliography of all Arctic literature, including permafrost.

The multitude of problems associated with frost action, as we refer to it in the United States, appropriately should accompany any discussion of permafrost. However, lack of space permits only a passing reference to the relationship of permafrost to frost action. An annotated bibliography on frost action has been prepared by the Highway Research Board (1948).

Thanks are due Louis L. Ray, P. S. Smith, Inna V. Poiré, Troy L. Péwé, David M. Hopkins, William S. Benninghoff, Joel H. Swartz, and D. J. Cederstrom, of the United States Geological Survey, and to Stephen Taber and Kirk Bryan for critical reading of this manuscript. These and others in the Geological Survey have provided many valuable suggestions for which individual acknowledgment is difficult. The use of unpublished manuscripts and notes of P. S. Smith and C. V. Theis is greatly appreciated.

PERMAFROST

The term "permafrost" was proposed and defined by Muller (1945). A longer but more correct phrase is "perennially frozen ground" (Taber, 1943a). The difficulties of the current terminology are presented by Bryan (1946a, 1946b), who proposed a new set of terms. These are discussed by representative geologists and engineers (Bryan, 1948). Such terms as cryopedology, congeliturbation, congelifraction, and cryoplanation have been accepted by some geologists (Denny and Sticht, unpublished manuscript; Judson, 1949; Cailleux, 1948; Troll, 1948) in order to attempt standardization of the terms regarding perennially frozen ground and frost action. The term permafrost has been widely adopted by agencies of the United States Government, by private organizations, and by scientists and laymen alike. Its use is continued here because it is simple, euphonious, and easily understood by all.

Extent.—Much of northern Asia and northern North America contains permafrost (fig. 1) (Jenness, 1949; Sumgin, 1947; Muller, 1945; Obruchev, 1945; Troll, 1944; Taber, 1943a; Cressey, 1939; and others).

The areal subdivision of permafrost into continuous, discontinuous, and sporadic bodies is already possible on a small scale for much of Asia, but as yet for only part of North America. Refinements in delineations of these zones are being made each year. The southern margin of permafrost is known only approximately, and additional isolated bodies are being discovered as more detailed work is undertaken. The southern margin of permafrost has receded northward within the last century (Obruchev, 1946).

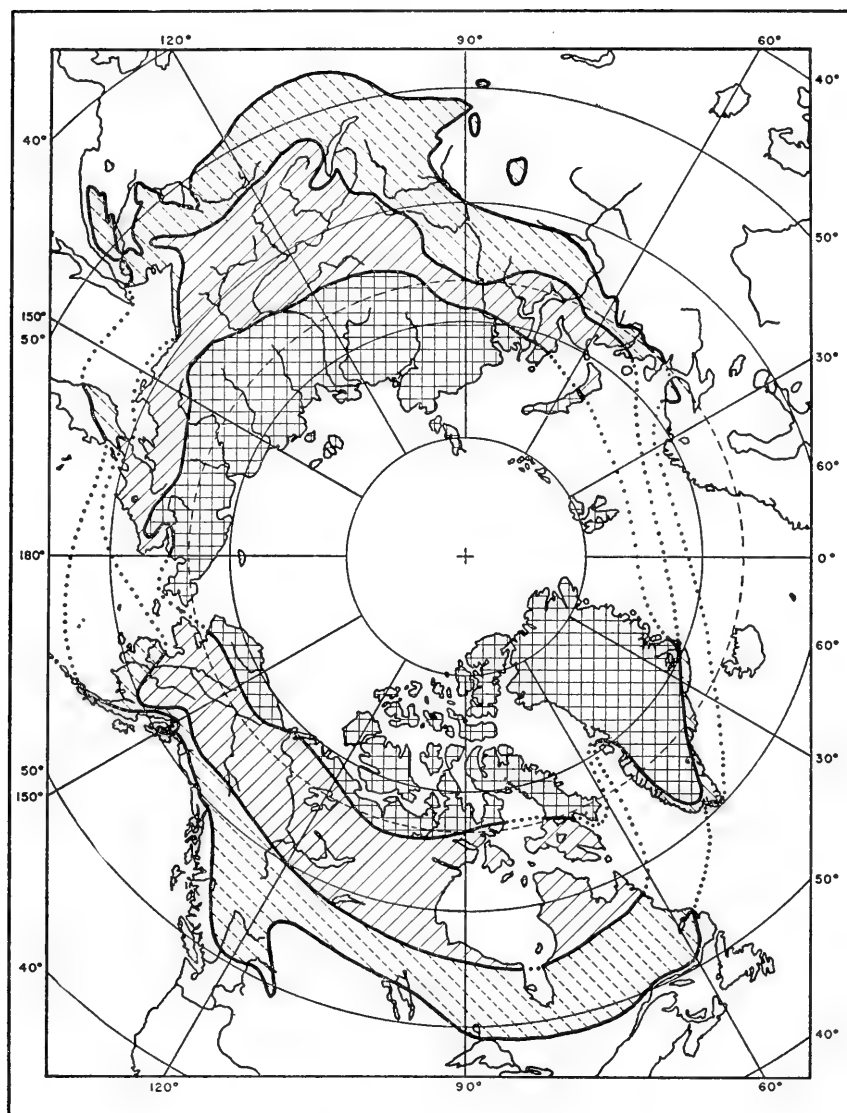


FIGURE 1.—Areal distribution of permafrost in the Northern Hemisphere.

Double hatching: Approximate extent of continuous permafrost. Ground temperature at a depth of 30 to 50 feet generally below -5°C . Diagonal hatching: Approximate extent of discontinuous permafrost. Ground temperature in permafrost at a depth of 30 to 50 feet generally between -5° and -1°C . Dotted diagonal hatching: Approximate extent of sporadic permafrost. Ground temperature in permafrost at a depth of 30 to 50 feet generally above -1°C . Reliability: Eurasia, good; Alaska, fair; all other, poor. (Eurasia after Sumgin and Petrovsky, 1940, courtesy of I. V. Poiré.)

Permafrost is absent or thin under some of the existing glaciers, and it may be absent in areas recently exhumed from ice cover.

A greater extent of permafrost in the recent geologic past is known by inference from phenomena now found to be associated with permafrost (H. T. U. Smith, 1949b; Horberg, 1949; Richmond, 1949; Schafer, 1949; Cailleux, 1948; Poser, 1948, 1947a, 1947b; Troll, 1947, 1944; Zeuner, 1945; Weinberger, 1944, and others). Some of the more important phenomena are fossil ground-ice wedges, solifluction deposits, block fields and related features, involutions in the unconsolidated sediments, stone rings, stone stripes and related features, and asymmetric valleys (H. T. U. Smith, 1949b). The presence of permafrost in earlier geologic periods can be inferred from the known facts of former periods of glaciation and from fossil periglacial forms.

In the Southern Hemisphere permafrost is extensive in Antarctica. It probably occurs locally in some of the higher mountains elsewhere, but its actual extent is unknown.

Thickness.—Permafrost attains its greatest known thickness of about 2,000 feet (620 meters) at Nordvik in northern Siberia (I. V. Poiré, oral communication). Werenskiöld (1923) reports a thickness of 320 meters (1,050 feet) in the Sveagruvan coal mine in Lowe Sound, Spitsbergen. In Alaska its greatest known thickness is about 1,000 feet, south of Barrow.

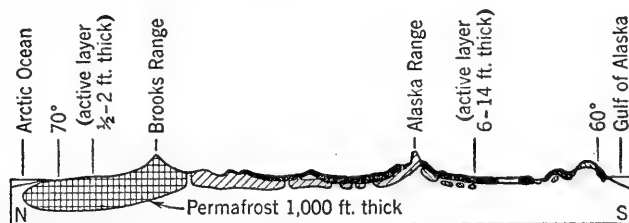
Generally the permafrost thins abruptly to the north under the Arctic Ocean. It breaks into discontinuous and sporadic bodies as it gradually thins to the south (fig. 2) (Muller, 1945; Taber, 1943a; Cressey, 1939; and others).

In areas of comparable climatic conditions today, permafrost is much thinner in glaciated areas than in nonglaciated areas (Taber, 1943a).

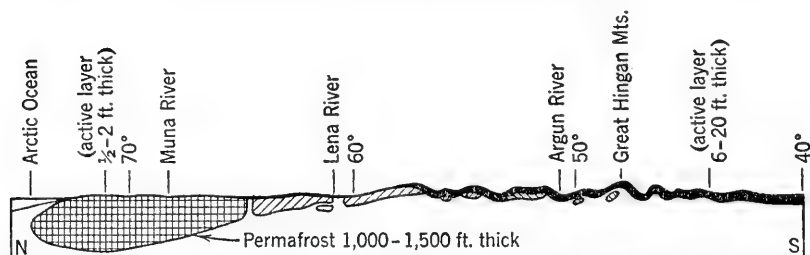
Unfrozen zones within perennially frozen ground are common near the surface (Muller, 1945) and are reported to occur at depth (Taber, 1943a; Cressey, 1939). They have been interpreted as indicators of climatic fluctuations (Muller, 1945; Cressey, 1939), or as permeable water-bearing horizons (Taber, 1943a).

Temperature.—The temperature of perennially frozen ground below the depth of seasonal change (level of zero annual amplitude) (Muller, 1945) ranges from slightly less than 0° C. to about -12° C. (I. V. Poiré, oral communication). In Alaska the minimum temperature recorded to date is -9.6° C. at a depth of 100 to 200 feet in a well about 40 miles southwest of Barrow (J. H. Swartz, 1948, written communication). Representative temperature profiles in areas of (1) continuous permafrost are shown in figure 3, *a*; of (2) discontinuous permafrost, figure 3, *b*; and of (3) sporadic bodies of permafrost, figure 3, *c*.

Temperature gradients from the base of permafrost up to the depth of minimum temperature vary from place to place and from time to time. In 1947-48 four wells in northern Alaska had gradients between 120 and 215 feet per degree centigrade (data of J. H. Swartz, G. R. MacCarthy, and R. F. Black).



Diagrammatic cross section through Alaska, along long. 150°, showing approximate distribution of permafrost and thickness of active layer



Diagrammatic cross section through Asia, along long. 120°, showing approximate distribution of permafrost and thickness of active layer. (Modified from unpublished cross section by I.V. Poire').



FIGURE 2.—Representative cross sections of permafrost areas in Alaska and Asia.

The shape of a temperature curve indicates pergelation or depergelation (aggradation or degradation of permafrost) (Muller, 1945; Taber, 1943a). Some deep temperature profiles have been considered by Russian workers to reflect climatic fluctuations in the recent geologic past. No known comprehensive mathematical approach has been attempted to interpret past climates from these profiles, although it seems feasible. Some of the effects of Pleistocene climatic variations on geothermal gradients are discussed by Birch (1948) and Ingersoll et al. (1948).

Character.—Permafrost is defined as a temperature phenomenon, and it may encompass any type of natural or artificial material, whether organic or inorganic. Generally permafrost consists of variable thicknesses of perennially frozen surficial unconsolidated materials, bedrock, and ice. Physical, chemical, or organic composition, degree of induration, texture, structure, water content, and the like range widely and are limited only by the extremes of nature or the

caprice of mankind. For example perennially frozen mammals, rodents, bacteria, artifacts, beds of sand and silt, lenses of ice, beds of peat, and varied junk piles, such as kitchen-middens, mine dumps, and ships' refuse heaps are individual items that collectively can be lumped under the term permafrost.

Ground perennially below freezing but containing no ice has been called "dry permafrost" (Muller, 1945).

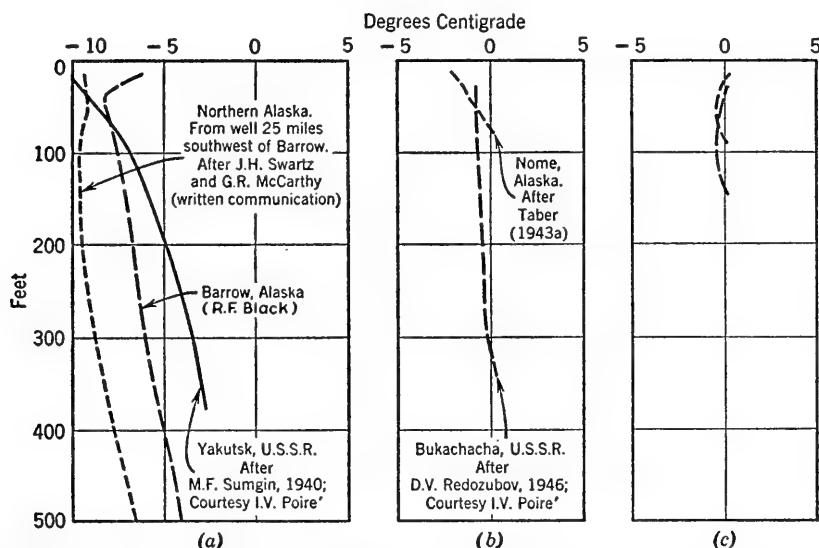
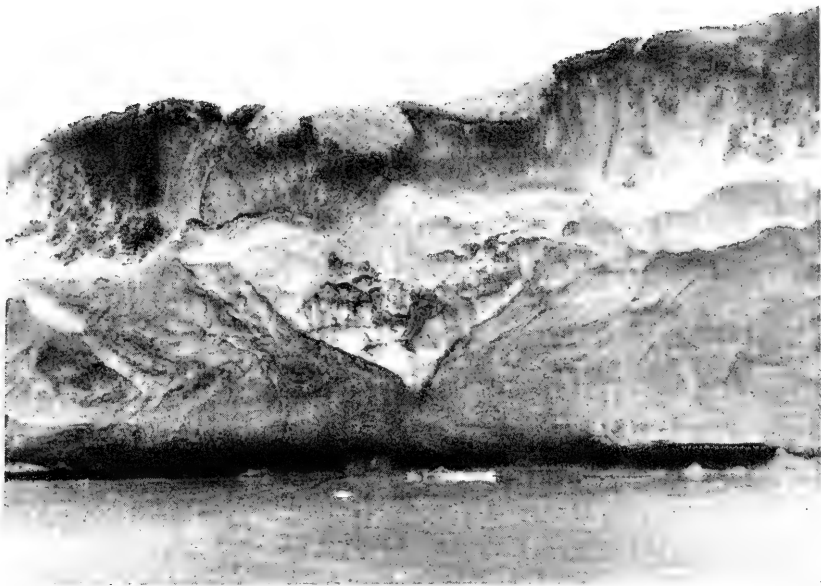


FIGURE 3.—(a) Representative temperature profiles in areas of continuous permafrost. (b) Representative temperature profiles in areas of discontinuous permafrost. (c) Hypothetical temperature profiles in areas of sporadic permafrost.

Permafrost composed largely of ice is abundant particularly in poorly drained fine-grained materials (pls. 1, 2, and 3). The ice occurs as thin films, grains, fillings, veinlets, large horizontal sheets, large vertical wedge-shaped masses, and irregular masses of all sizes. Many masses of clear ice are arranged in geometric patterns near the surface, that is, polygonal ground (pl. 4) and honeycomb structure. The ice may be clear, colorless, yellow, or brown. In many places it contains numerous oriented or unoriented air bubbles (pl. 5, fig. 1), and silt, clay, or organic materials. Size, shape, and orientation of the ice crystals differ widely (pl. 5, fig. 2). Discordant structures in sediments around large masses of ice are evidences of growth (Taber, 1943a; Leffingwell, 1919).

Relation to terrain features.—In the continuous zone of permafrost the upper limit (permafrost table, Muller, 1945) is generally within a few inches to 2 feet of the surface. Large lakes and a few large rivers lie in thawed areas slightly larger than the basins they occupy



1. Ground ice in the form of an ice wedge and in undifferentiated types exposed in a sea-cut silt bank 23 feet high, about 75 miles southeast of Barrow, Alaska. Photographed August 7, 1950.

(All photographs by the author unless otherwise stated.)



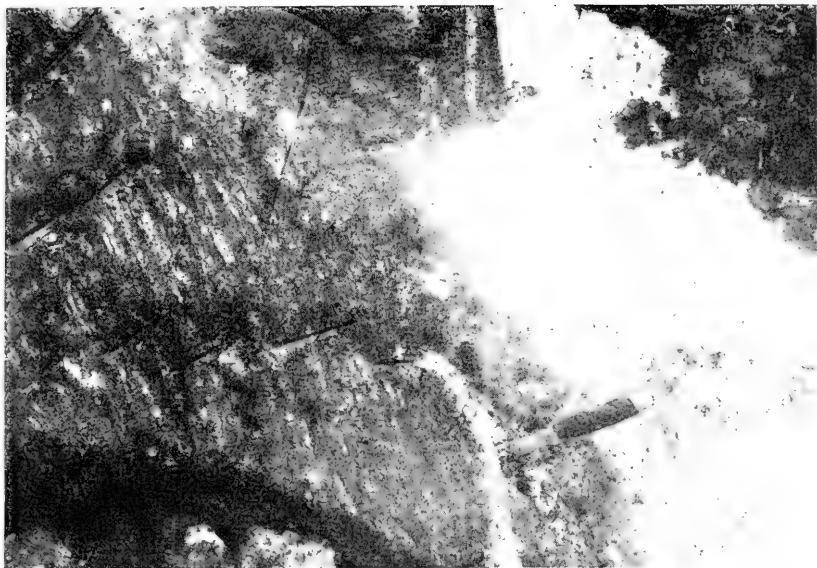
2. Irregular masses of ice and ice wedges exposed by placer operations in "muck" deposits at Fairbanks Creek, Fairbanks, Alaska. Photographed July 12, 1948.



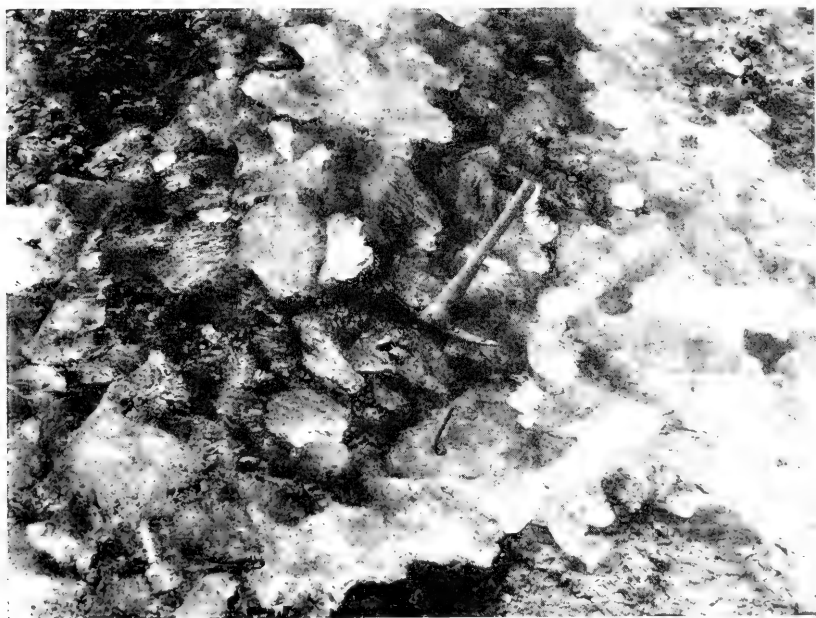
1. Horizontal layer of blue ice and vertical ice wedge exposed by placer operations in "muck" deposits in Fairbanks Creek, Fairbanks, Alaska. Photographed July 12, 1948.



2. Three horizons of buried young trees in "muck" with considerable ice exposed by placer operations on Fairbanks Creek, Fairbanks, Alaska. Photographed July 12, 1948.



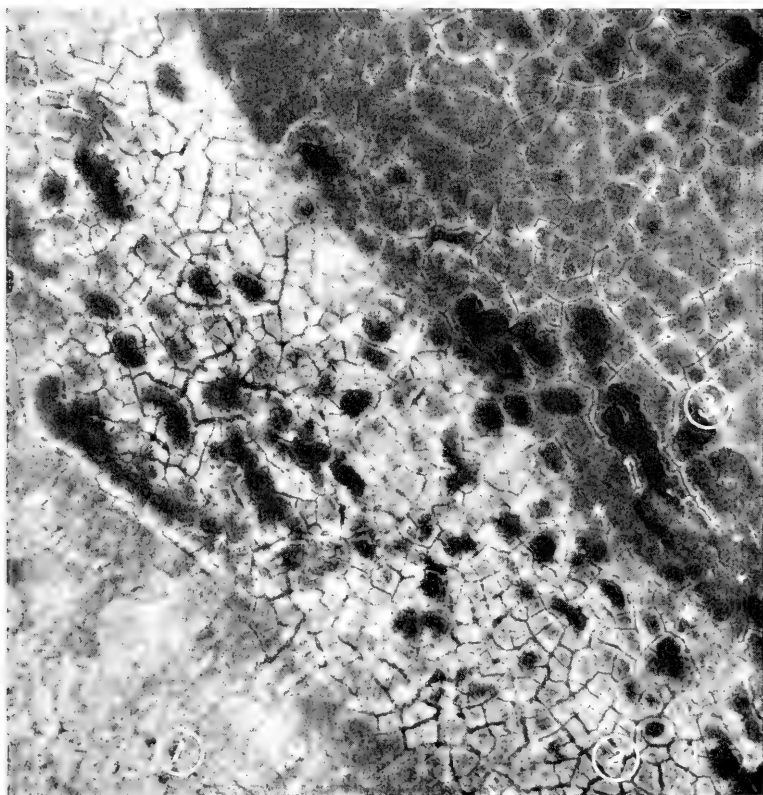
1. Thin veinlets, granules, and large mass of clear ice in organic-rich silt deposit near Barrow, Alaska. Photographed July 31, 1947.



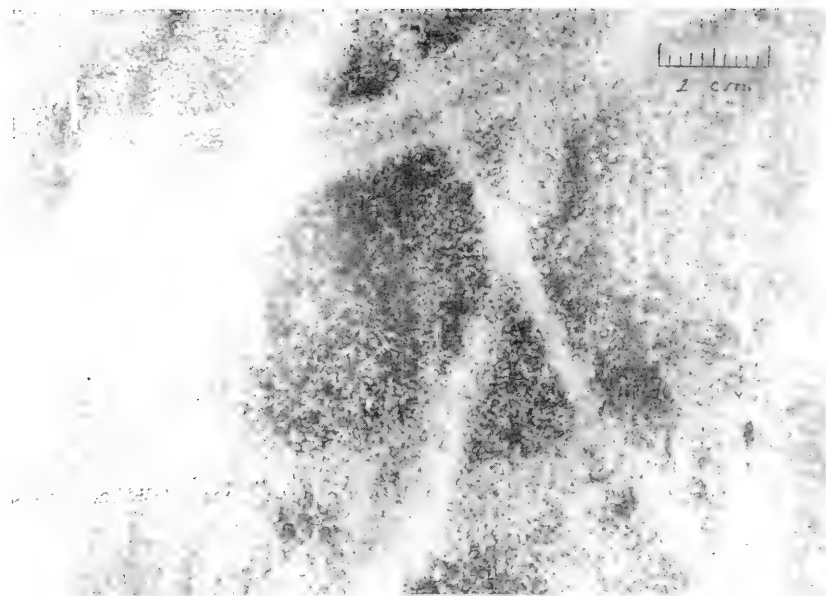
2. Large individual crystals of ice in permafrost at a depth of about 20 feet in "muck" exposed by placer operations at Fairbanks Creek, Fairbanks, Alaska. Photographed July 2, 1950.



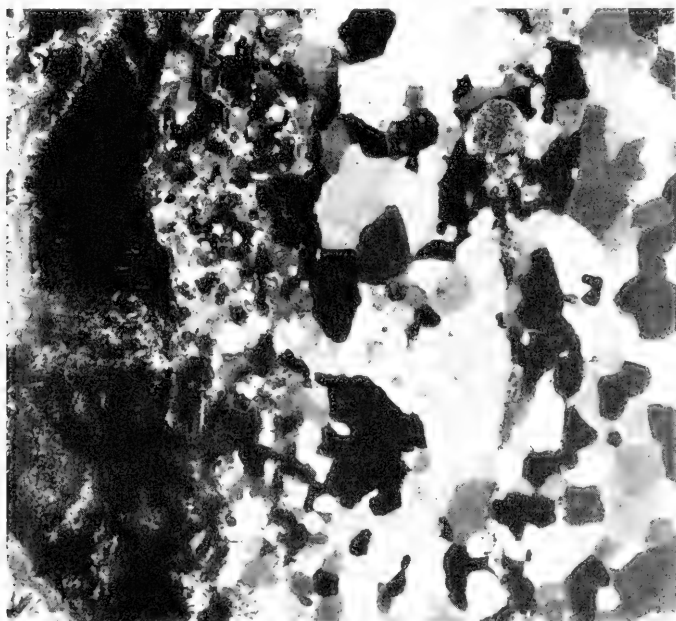
1. Ice-wedge polygons and ground ice in 15-foot sand bank exposed by wave action on the south side of Admiralty Bay, about 45 miles southeast of Barrow, Alaska. Photographed August 28, 1947.



2. Ice-wedge polygons of three distinct stages in surficial expression on coastal plain near Barrow, Alaska. Zone 1, containing high-centered polygons, is oldest; zone 2 is intermediate to zone 3, the youngest, with low-centered polygons. Photographed July 20, 1947, by the U. S. Coast and Geodetic Survey.



1. Thin section of ground ice from an ice wedge near Barrow, Alaska, showing numerous air bubbles. Photographed January 23, 1950.



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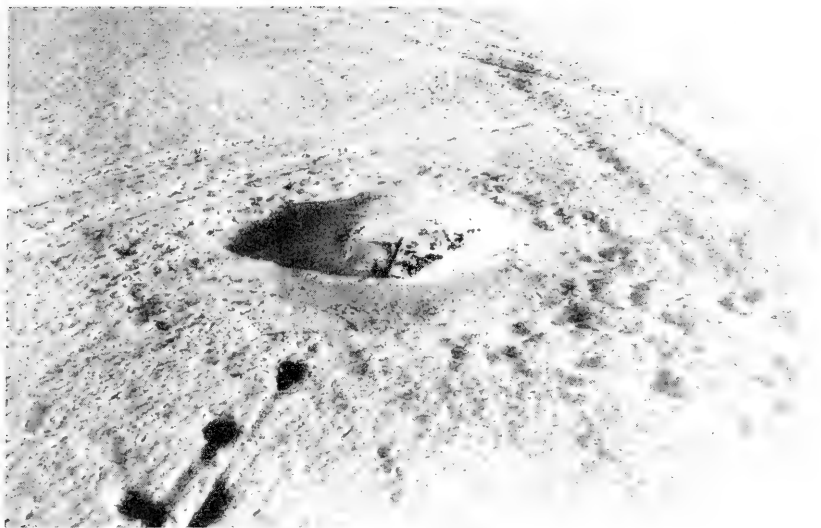
2. Thin section of ground ice from an ice wedge near Barrow, Alaska, showing silt and individual ice crystals by using transmitted light and crossed polaroids. Photographed April 21, 1950.



1. Soil creep in solifluction lobes on rounded hill at "12-mile Summit" on Steese Highway, about 87 miles by road northeast of Fairbanks, Alaska. Photographed July 5, 1948.



2. Landslide on top of thawing permafrost on Slana-Tok Cut-off, 27.9 miles from Gakona in east-central Alaska. Photographed July 9, 1946.



1. Ice laccoliths (small ground-ice mound, small pingo, or frost blister) produced by the heaving of the active layer by the hydrostatic pressure of water trapped between downward-progressing seasonal frost and permafrost in a swampy lake bed, near Barrow, Alaska. Four inches of moss and other vegetation covers a plano-convex disk about 15 inches thick and 5 feet in diameter. Photographed October 4, 1949.



2. Peat mound (frost mound), partially dissected by slumping along a lake about 25 miles southeast of Barrow, contains several bodies of clear ice underlying peat. The ice was introduced in part by filling by sublimation in horizontal contraction cracks and in part by forceful injection of water along a zone between the active layer and permafrost. Photographed August 21, 1946.



1. Thermokarst or cave-in lake about 10 miles east of Mentasta Lake on the Siana-Tok Cut-off in east-central Alaska. Photographed July 9, 1946.



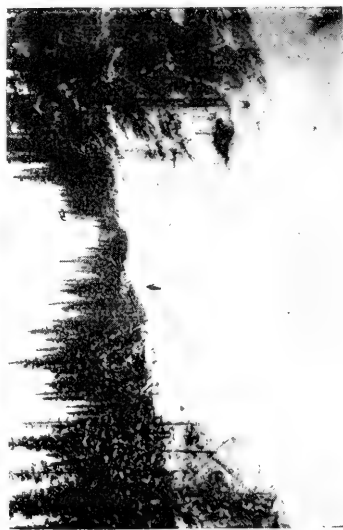
2. Pingo, estimated 60 feet high, on the coastal plain of northern Alaska, about 30 miles north of Umiat, Alaska. Photographed September 17, 1945.



1. Caving polygons near Barrow, with relief of 4 to 8 feet, resulting from the thawing of ice wedges after the protecting mat of tundra vegetation has been removed. Photographed August 25, 1947.



2. Ground ice in foundation excavation near Barrow. Concrete in forms is being heated to permit setting on top of permafrost. Photographed July 15, 1947.



Upper: Left, irregular settling of Kougarok Railroad on frozen tundra about 7 miles north of Nome, Alaska; photographed August 10, 1948. Right, caving and irregular settling in gravel fill over thawing ice wedges in runway at Umiat, Alaska; photographed August 30, 1946.
Lower: Left, road icing, about 4 feet thick, on Slana-Tok Cut-off about 58.7 miles north of Slana in east-central Alaska; photographed February 27, 1946. Right, earth mounds 4 to 8 feet high produced by stripping of vegetation in farming and subsequent thawing of ice wedge polygons near College, Alaska; photographed September 19, 1948.



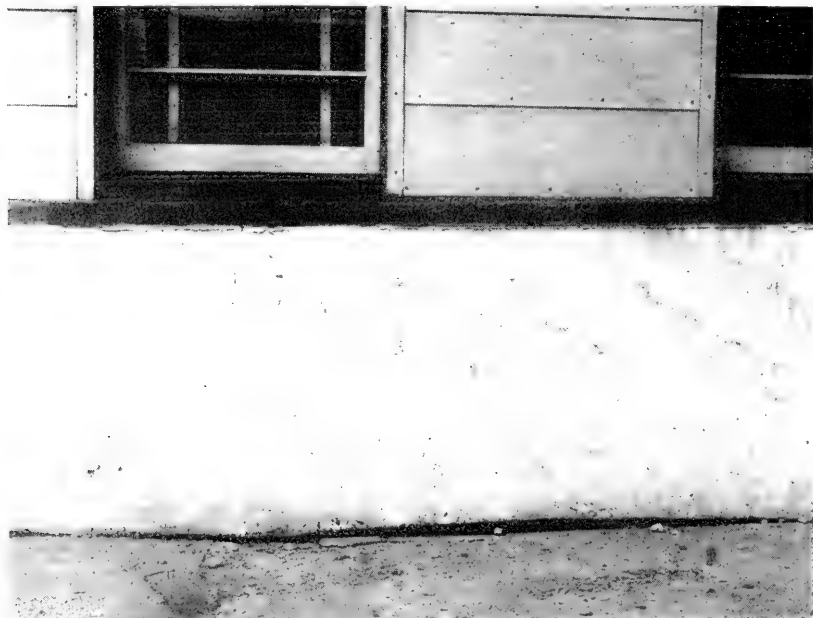
1. Bridge piling on the Alaska Railroad broken by downhill creep in mud on top of permafrost in the Nenana River Gorge, central Alaska. Photographed September 24, 1948.



2. Slump in gravel on street in Barrow, where steam line produced thawing of permafrost. Photographed May 12, 1950.



1. Mud flow on top of permafrost along the Alaska Railroad resulting in track settling, near Moody, Alaska. Photographed June 22, 1948.



2. Settling cracks in foundation wall of the U. S. Post Office, Nome, Alaska, after thawing of permafrost under the building. Photographed August 10, 1948.

(Black and Barksdale, 1949; Muller, 1945). Well-drained coarse-grained materials may thaw annually to a depth of 6 feet. Poorly drained fine-grained materials protected from solar radiation and insulated with moss and other vegetation may thaw annually to a depth of only 4 inches.

In the discontinuous zone permafrost is absent under most major rivers and lakes. It may be absent in the tops of some well-drained low hills. Seasonal thaw (active layer, Muller, 1945) penetrates 1 foot to 10 feet, depending on insulation, insolation, drainage, and type of material.

Sporadic bodies of permafrost may be relics below the active layer or may be forming in favorable situations in poorly drained fine-grained materials on north-facing slopes. In the zone of sporadic permafrost the active layer may or may not reach the permafrost table, and it ranges between 2 and 14 feet in thickness.

Generally the depth of thaw is at a minimum in northern latitudes and increases to the south. It is at a minimum in peat or highly organic sediments and increases successively in clay, silt, and sand to a maximum in gravelly ground or exposed bedrock. It is less at high altitudes than at low altitudes; less in poorly drained ground than in dry well-drained ground; at a minimum under certain types of tundra and increases successively in thickness under areas of bog shrubs, black spruce, larch, white spruce, birch, aspen, and poplar to a maximum under tall pines. It is less in areas of heavy snowfall; less in areas with cloudy summers; and less on north-facing slopes (Muller, 1945; Troll, 1944; Taber, 1943a; and others).

Works of man commonly upset the natural thermal equilibrium and may tend to destroy permafrost or to aid in its formation. Most roads, runways, and other structures on the surface of or in the ground generally have lower permafrost tables than undisturbed natural areas adjacent to them. Structures above the ground and insulated from the ground protect the surface from solar radiation and commonly produce higher permafrost tables.

Origin.—The origin of perennially frozen ground is discussed by Jenness (1949), Muller (1945), Zeuner (1945), Taber (1943a), Cressey (1939), Nikiforoff (1932), Leffingwell (1919), and others. Generally it can be stated that most sporadic bodies of permafrost are relics of colder climates. Discontinuous bodies of permafrost are largely relics, but under favorable conditions may grow in size, and new deposits are being perennially frozen. In areas of continuous permafrost, heat is being dissipated actively from the surface of the earth to the atmosphere, and new deltas, bars, landslides, mine tailings, and other deposits are being pergelated (incorporated in the permafrost) (Bryan, 1946a).

Local surface evidences indicate that heat, in some places at least, is being absorbed at the base of permafrost faster than it is being dissipated at the surface (Hopkins, 1949; Young, 1918). Hence the cold reserve is being lessened, and the thickness of permafrost is decreasing from the base upward.

The mean annual air temperature required to produce permafrost undoubtedly varies many degrees because of local conditions. Generally it is given as 30° to 24° F.; theoretically permafrost can form above 32° F. (Theis, unpublished manuscript), and apparently it is doing so locally in parts of southwest Alaska where poor drainage, abundant vegetation, cloudy summers, and low insolation are found (S. Abrahamson, oral communication, and Ernest H. Muller, written communication).

The relative effects of past climates have been inferred qualitatively through a study of present temperature profiles and indirectly through a study of past deposits, pollen analysis, vegetal changes, structural soils, and blockfields.

The origin of large, clear ice masses in the permafrost is a special problem in itself. Numerous theories are extant, and one or more may apply to a particular mass of ice (Taber, 1943a; Leffingwell, 1919; and others).

GEOLOGIC RAMIFICATIONS

Throughout the Arctic and sub-Arctic the role of permafrost is extremely important. As an impervious layer in continuous permafrost zones, it exerts a drastic influence on surface waters, completely prevents precipitation from entering the natural ground-water reservoirs, and commonly causes a concentration of organic acids and of mineral salts in suprapermfrost water. In discontinuous permafrost zones, and less so in areas of sporadic permafrost, ground-water movements are interrupted or channelized. Quality of water, too, can be materially affected by the storage for centuries and subsequent release by thawing of organic and inorganic materials (Kaliaev, 1947). In fact, our present conceptions of ground-water reservoirs, ground- and surface-water movements, infiltration, quality of water, and so on must be reevaluated in considering permafrost as a new geologic formation, generally not uniform in composition or distribution, that transcends all rock and soil formations. Furthermore, it must be considered as much in the light of past as of present conditions.

It is well known that in cold climates physical disintegration (frost-splitting, congelifraction) plays a more important role than chemical weathering. The repeated freezing of water-saturated materials and the growth of ice crystals in numerous small pores, cracks, joints, cleavage planes, or partings is by far the most effective destructive process. Taber (1943a) has shown that, without water, disintegration

is generally much slower. Permafrost is one of the most important agents in keeping the soils supersaturated (containing more water than pore space—a suspension) and in keeping many rock fragments wet.

It is less widely known that mass-wasting processes in the Arctic and sub-Arctic are instrumental in the transport of tremendous volumes of material. With the exception of unbroken bedrock, the materials on the surface of slopes greater than 1° to 3° are on the move everywhere in summer. The amount of material involved and the rapidity of such movements impress all who have studied them (Washburn, 1947, and others).

Permafrost, on thawing slightly in summer, supplies a lubricated surface and additional water to materials probably already saturated. Hence solifluction (pl. 6, fig. 1), mud flows (pl. 6, fig. 2), and other gravity movements take place with ease and, in favorable locations, even supply material to streams faster than the streams can remove it (Wahrhaftig, 1949, and others). Bryan (1949) has coined the term "cryoplanation" to cover such processes, including also frost-heaving normal to slopes and settling vertically, which in the Arctic are instrumental in reducing the landscape to long, smooth slopes and gently rounded forms. Such physiographic processes are only partly understood and their effects only qualitatively known (Bryan, 1949).

Permafrost, by aiding in maintaining saturated or supersaturated conditions in surficial materials, indirectly aids in frost-stirring (congeliturbation), frost-splitting, and mass-wasting processes so that, in places, bedrock is disintegrated, reduced in size, thoroughly mixed, and rapidly transported. The result is a silt-sized sediment that is widespread in the Arctic. Various authors (Bryan, 1949; Hopkins, 1949; P. S. Smith, unpublished manuscript; Zeuner, 1945; Taber, 1943a; Tuck, 1940) disagree as to whether some of the material is derived from eolian, lacustrine, or local frost-splitting and mass-wasting processes. Size-grade-distribution curves, mineral comparisons, chemical analyses, comparisons with glacial materials and with organic materials, etc., have been used by various investigators to prove their point, but the differences of opinion have by no means been resolved.

Frost action (frost-heaving, frost-stirring, and frost-splitting) and gravity movements result in many surface forms that are found most abundantly in areas of permafrost, i. e., *strukturboden*, involutions, frost boils, hummocks, altiplanation terraces, terrecettes, and soil stripes (Judson, 1949; Richmond, 1949; Schafer, 1949; H. T. U. Smith, 1949; Cailleux, 1948; Troll, 1948, 1947, 1944; Washburn, 1947; Conrad, 1946; Zeuner, 1945; Taber, 1943a; Sharp, 1942b; Gatty et al., 1942; Steche, 1933; Högbom, 1914; and others). Annual freezing in permafrost areas also forces changes in surface- and ground-water

migration and commonly results in pingos, frost blisters, ice mounds, icings, aufeis, and other related forms (Muller, 1945; Troll, 1944; Sharp, 1942a; Mullis, 1930). (Pl. 7 and pl. 8, fig. 2). Many of the forms produced by frost action and seasonal freezing are closely related in character and origin; however, the lack of a standardized terminology for these features produces a perplexing picture.

Little can be said quantitatively regarding the importance of frost action (and indirectly permafrost) in ancient sediments and soils (Zeuner, 1945). Throughout the world, deposits of former glaciers have been found in the stratigraphic column. They indicate many periods of glaciation and, hence, cold climates. Undoubtedly permafrost was present during those times. Fossil forms derived from frost and permafrost are known (Horberg, 1949; Judson, 1949; Richmond, 1949; Schafer, 1949; H. T. U. Smith, 1949b; Wahrhaftig, 1949; Zeuner, 1946, 1945; Troll, 1944; and others). These forms provide data on the processes producing the surficial materials and on the environment of deposition. These features are only now being recognized and studied in the detail that is warranted (Bryan, 1949).

Permafrost throughout the world has provided an outstanding wealth of material for paleontologists and archeologists (Hibben, 1941). In perennially frozen Alaskan placers alone, investigators have found more than 27 different plants (Chaney and Mason, 1936), including whole forests of buried stumps (Giddings, 1938); numerous iron and other bacteria; algae; 87 species of diatoms (Taber, 1943a); bones of at least 20 species of large mammals, represented by tens of thousands of specimens (Taber, 1943a; Wilkerson, 1932); numerous species of rodents; and a few species of mollusks, sponges, and insects (Taber, 1943a). Permafrost in Siberia has been a storehouse for Pleistocene mammals (Tolmachoff, 1929).

Permafrost upsets many readings taken by geophysicists in determining the internal constitution of the earth. Velocities of seismic waves, for instance, are materially increased by frozen ground containing much ice and may result in considerable errors in determinations of depths. Although the actual increases are not definitely known, they probably fall within the range of 1,000 to 8,000 feet per second (J. H. Swartz, oral communication). Unfortunately, the lower contact of permafrost causes, with present equipment, no satisfactory reflections or refractions. Seismic methods cannot be used to determine the thickness or variability of the zone distorting the seismic waves. Difficulties in drilling, preparing the explosive charges, checking the ground waves, and getting interpretable effects are augmented in permafrost areas.

Electrical methods, particularly the resistivity methods, have given promise of solving some of the difficulties in determining the extent

and thickness of permafrost (Enenstein, 1947; Swartz and Shepard, 1946; Muller, 1945; and Joestings, 1941). Generally resistivities of frozen silt and gravel are several thousand ohms higher than comparable unfrozen materials and may be 20 to 120 times as high (Swartz and Shepard, 1946; Joestings, 1941). However, it is well known that the type of material is less important than the amount of unfrozen ground water and dissolved salts within the material. Even in frozen ground these factors are so variable that resistivity data can be interpreted with reliability only by experienced men and generally only in areas where some positive checks can be made through drilling.

Sumgin and Petrovsky (1947) discuss a new radio-wave technique used where permafrost is below -5°C .

ENGINEERING SIGNIFICANCES

In Alaska during World War II the difficulties encountered by our armed forces in obtaining permanent water supplies and in constructing runways, roads, and buildings in permafrost areas focused attention on permafrost as nothing else could (Wilson, 1948; Jaillite, 1947; Barnes, 1946; Taber, 1943b). Only then did most people realize that in Russia similar difficulties with railroads, roads, bridges, houses, and factories had impeded colonization and development of the north for decades. Now with the recent progress in aviation, and because of the strategic importance of the north, active construction and settlement for military and civilian personnel must increase, and the problems of permafrost must be solved.

Fortunately we can draw on the vast experience of the Soviet Union. Their engineers have shown that it is—

... a losing battle to fight the forces of frozen ground simply by using stronger materials or by resorting to more rigid designs. On the other hand, the same experience has demonstrated that satisfactory results can be achieved and are allowed for in the design in such a manner that they appreciably minimize or completely neutralize and eliminate the destructive effect of frost action ... Once the frozen ground problems are understood and correctly evaluated, their successful solution is for the most part a matter of common sense whereby the frost forces are utilized to play the hand of the engineer and not against it. ... it is worth noting that in Soviet Russia since about 1938 all governmental organizations, municipalities, and cooperative societies are required to make a thorough survey of the permafrost conditions according to a prescribed plan before any structure may be erected in the permafrost region. [Muller, 1945, pp. 1-2, 85-86.]

Specifically we must think of permafrost in construction of buildings, roads, bridges, runways, railroads, dams, and reservoirs, in problems of water supply, sewage disposal, telephone lines, drainage, excavation, ground storage, and in many other ways. Permafrost can be used as a construction material or as a base for construction, but steps

must be taken to insure its stability. Otherwise it must be destroyed and appropriate steps taken to prevent it from returning.

BIOLOGIC SIGNIFICANCES

Permafrost, by means of its low temperature and ability to prevent runoff, is a potent factor that aids in controlling vegetal growth in the Arctic and sub-Arctic (Mosley, 1937). Many places have semi-arid climate yet have luxuriant growths of vegetation because the permafrost prevents the loss of precipitation through underground drainage (low evaporation is possibly as important). Such conditions are natural breeding environments for mosquitoes and other insects.

Conversely, luxuriant growths of vegetation, by insulating the permafrost in summer, prevent deep thawing and augment cold soil temperatures. Hence those species with deep root systems, such as certain trees, are dwarfed or absent, and nourishment available to smaller plants is limited.

Raup (1941, 1947) and Griggs (1936) point out that much of Arctic soil is unstable because of frost action (commonly associated with permafrost) and that standard biological methods describing plant communities do not apply. The normal associations have been greatly disturbed, special communities for different frost forms can be identified, and above all the plant communities must be described on the basis of their physical habitat.

Permafrost probably controls the distribution of some animal species, such as the frogs or toads, that require thawed ground into which they can burrow for the winter. Foxes can have dens only in dry elevated places where the depth of thaw is 2 feet or more. Similarly, permafrost affects worms, burrowing insects, and other animals that live in the ground.

Indirectly, permafrost, by exercising some control on types of vegetation, that is, tundra vs. forest, also determines the distribution of grazing animals such as the reindeer and Barren Ground caribou.

FACTORS AFFECTING PERMAFROST

Most major factors affecting permafrost are recognized qualitatively, but none is well known quantitatively. These factors are easily visualized by turning to the original definition of the term "permafrost." As permafrost is fundamentally a temperature phenomenon, we may think of it as a negative temperature produced by climate in material generally of heterogeneous composition. Permafrost is produced because, through a combination of many variables more heat is removed from a portion of the earth during a period of

two or more years than is replaced. Hence a cold reserve is established.

Basically the process can be reduced to one of heat exchange between the sun, the atmosphere, and the earth. The sun, through solar radiation (insolation), and the interior of the earth, primarily through conduction, supply practically all primary heat to the surface of the earth (biological processes, natural or artificial fires, chemical reactions, cosmic or other radiations excepted). This primary heat is dissipated to the atmosphere and to outer space by conduction, radiation, convection, and evaporation. The atmosphere, by warm winds and precipitation, also distributes secondary heat to the surface of smaller areas.

We know that earth temperatures at the depth of seasonal change are in most places within a few degrees of the mean annual air temperature, and that a geothermal gradient is established from the surface to the interior of the earth. The geothermal gradient at any one place is relatively fixed from year to year, though it varies from place to place and has changed markedly during geologic time. It is generally considered as 1° F. for each 60 to 110 feet of depth in sedimentary rock in the United States (Orstrand, 1939); possibly 0.1 to 0.2 calorie per square centimeter per day is transmitted to the surface from the interior. In contrast the sun supplies possibly as much as several hundred calories per square centimeter per day to the surface, depending primarily on the season and secondarily on cloudiness, humidity, altitude, latitude, and other factors. This period of rapid heating, however, is very short in the Arctic, and for many months heat is dissipated to the atmosphere and outer space. When dissipation of heat outweighs input, a cold reserve is produced. If the cold reserve remains below freezing for more than 2 years, it is called permafrost.

Although the fundamental thesis of the problem is simple, its quantitative solution is exceedingly complex. In only a few isolated areas in the Arctic do we know anything of the geothermal gradients in and below permafrost. The climate (including insolation) is so incompletely known that at present it is not possible to evaluate climatic factors except in a general way as they effect primary or secondary heat or dissipation of heat (Lane, 1946, and others). Thus it is well known that the following conditions tend to produce permafrost:

1. Long, cold winters and short, cool summers.
2. Low precipitation the year around and especially low snowfall.
3. Clear winters and cloudy summers.
4. Rapid evaporation the year around.
5. Strong, cold winds in summer and winter.
6. Low insolation.

The materials involved have different specific heats and different heat conductivities (Shannon and Wells, 1947; Muller, 1945; W. O. Smith, 1942, 1939). Chemical and physical properties vary widely, yet are of primary importance (W. O. Smith, 1942; Taber, 1930a, 1930b). Water transmits heat about 25 times as fast as air, and ice 4 times as fast as water. Thus, poorly drained silt and muck are much more easily frozen than dry, coarse-grained gravel. W. O. Smith (1942) points out the marked effect of soil structures and of architecture of pore space on thermal resistance in natural soils.

The dissipating surface of the earth is even more complex and more changeable. Water-saturated frozen vegetation and soil (bare of snow) in winter is an active conductor, whereas lush dry vegetation and dry porous soil in summer is an excellent insulator. Black-top pavements are good conductors and heat absorbers in summer and can destroy permafrost. An elevated and insulated building with circulating air beneath may unbalance the thermal regime of the ground toward pergelation. Heat conductivities of some earth materials under fixed laboratory conditions are known, but the quantitative effect in nature of variable moisture conditions and of changing vegetation is not. Changes in the volume, composition, or temperature of ground water or surface runoff have effects as yet little known qualitatively or quantitatively.

All these factors must be considered to be in a delicate balance between freezing and thawing. It is to be emphasized that the thermal regime is not uniform, but changes from hour to hour, day to day, week to week, year to year, and cycle to cycle. Specifically we must think in terms of geographic position, topography, lithology, structure, and texture of soils and bedrock, hydrology, geothermal gradients, thermal conductivities, vegetation, climate (temperature, precipitation, cloudiness, wind, insolation, evaporation), and cultural features.

What effect cosmic dust clouds, changes in carbon-dioxide content of the atmosphere, inclination of the earth's axis, eccentricity of the earth's orbit, sunspots, etc., have on permafrost can be surmised only as they affect insolation and dissipation of the earth's heat.

PRACTICAL APPLICATION AND SOLUTION OF THE PROBLEMS

In a permafrost area, it is imperative that the engineer have a complete understanding of the extent, thickness, temperature, and character of the permafrost and its relation to its environment before construction of any buildings, towers, roads, bridges, runways, railroads, dams, reservoirs, telephone lines, utilidors, drainage ditches and pipes, facilities for sewage disposal, establishments for ground-water supply, excavations, foundation piles, or other structures. The practical importance of the temperatures of permafrost cannot be overemphasized.

A knowledge of whether permafrost is actively expanding, or the cold reserve is increasing, is stabilized, or is being destroyed is essential in any engineering problem. Past experience has amply demonstrated that low cost or high cost, success or failure, is commonly based on a complete understanding of the problems to be encountered. Once the conditions are evaluated, proper precautions can be taken with some assurance of success.

Muller (1945) and Liverovsky and Morosov (1941) give comprehensive outlines of general and detailed permafrost surveys as adapted to various engineering projects. These outlines include instructions for the planning of the surveys, method of operation, and data to be collected. Rarely does the geologist or engineer on a job encounter "cut and dried" situations, and it is obvious that discretion must be exercised in modifying the outlines to meet the situation at hand.

In reconnaissance or preliminary survey to select the best site for construction in an unknown area, it is recommended that the approach be one of unraveling the natural history of the area. Basically the procedure is to identify each land form or terrain unit and determine its geologic history in detail. Topography, character and distribution of materials, permafrost, vegetation, hydrology, and climate are studied and compared with known areas. Then inferences, deductions, extrapolations, or interpretations can be made with reliability commensurate with the type, quality, and quantity of original data.

Thus the solution of the problems depends primarily on a complete understanding of the thermal regime of the permafrost and active layer. No factor can be eliminated, but all must be considered in a quantitative way. It is understandable that disagreement exists on the mean annual air temperature needed to produce permafrost. Few, if any, areas actually have identical conditions of climate, geology, and vegetation; hence, how can they be compared directly on the basis of climate alone? Without doubt the mean annual temperature required to produce permafrost depends on many factors and varies at least several degrees with variations in these factors. For practical purposes, however, units (terrain units) in the same climate or in similar climates may be separated on the basis of geology and vegetation. Thus there is a basis for extrapolating known conditions into unknown areas.

The advantages of aerial reconnaissance and study of aerial photographs for preliminary site selection are manifold. Aerial photographs in the hands of experienced geologists, soils engineers, and botanists can supply sufficient data to determine the best routes for roads and railroads, the best airfield sites, and data on water supply, construction materials, permafrost, trafficability conditions, camouflage, and other problems. Such an approach has been used with

success by the Geological Survey and other organizations and individuals (Black and Barksdale, 1949; Wallace, 1948; Woods et al., 1948; Pryor, 1947).

Emphasis is placed on the great need for expansion of long-term applied and basic research projects as outlined by Jaillite (1947) and referred to by Muller (1945) for a clearer understanding and evaluation of the problems.

Recognition and prediction.—Recognition and prediction of permafrost go hand in hand in a permafrost survey. If natural exposures of permafrost are not available along cut banks of rivers, lakes, or oceans, it is necessary to dig test pits or drill holes in places to obtain undisturbed samples for laboratory tests and to determine the character of the permafrost.

Surface features can be used with considerable degree of accuracy to predict permafrost conditions if the origin of the surface forms are clearly understood. Vegetation alone is not the solution, but it can be used with other factors to provide data on surficial materials, surface water, character and distribution of the permafrost, and particularly on the depth of the active layer (Denny and Raup, unpublished manuscript; Stone, 1948; Muller, 1945; Taber, 1943a). Cave-in or thermokarst lakes (pl. 8, fig. 1), thaw sinks (Hopkins, 1949; Black and Barksdale, 1949; Wallace, 1948; Muller, 1945), and ground-ice mounds (Sharp, 1942a) are particularly good indicators of fine-grained materials containing much ground ice. Polygonal ground can be used with remarkable accuracy also if the type of polygonal ground and its origin are clearly known. Numerous types of *strukturboden*, polygonal ground, and related forms have been described and their origins discussed (Wittmann, 1950; Richmond, 1949; Cailleux, 1948; Washburn, 1947; Troll, 1944; Sharp, 1942b; Högbom, 1914). The type of ice-wedge polygon described by Leffingwell (1919) (pl. 4) can be delimited from others on the basis of surface expression. The author's work in northern Alaska (1945 to present) reveals that the polygons go through a cycle that can be described as youth, maturity, and old age—from flat surface with cracks to low-centered polygons and, finally, to high-centered polygons. Size and shape of polygons, widths and depths of troughs or cracks, presence or absence of ridges adjacent to the troughs, type of vegetation, and other factors all provide clues to the size-grade of surficial materials and the amount of ice in the ground. Frost mounds, frost blisters, icings, gullies, and many other surficial features can be used with reliability if all factors are considered and are carefully weighed by the experienced observer.

Geophysical methods of locating permafrost have given some promise (Sumgin and Petrovsky, 1947; Enenstein, 1947; Swartz and Shepard, 1946; Muller, 1945; Joestings, 1941). (See p. 282.) Various

temperature-measuring and recording devices are employed. Augers and other mechanical means of getting at the permafrost are used (Muller, 1945, and others).

Construction.—Two types of construction methods are used in permafrost areas (Muller, 1945). In one, the passive method, the frozen-ground conditions are undisturbed or provided with additional insulation, so that the heat from the structure will not cause thawing of the underlying ground and weaken its stability. In the other method, the active method, the frozen ground is thawed prior to construction, and steps are taken to keep it thawed or to remove it and to use materials not subject to heaving and settling as a result of frost action. A preliminary examination, of course, is necessary to determine which procedure is more practicable or feasible.

Permafrost can be used as a construction material (if stress or load does not exceed plastic or elastic limit), removed before construction, or controlled outside the actual construction area. Muller (1945) has shown that it is best to distinguish (*a*) continuous areas of permafrost from (*b*) discontinuous areas and from (*c*) sporadic bodies. Russian engineers recommend that in (*a*) only the passive method of construction be used; in (*b*) or (*c*) either the passive or active method can be used, depending on thickness and temperature of the permafrost. Detailed information and references on the construction of buildings, roads, bridges, runways, reservoirs, airfields, and other engineering projects (pls. 9, 10, 11, and 12) are presented by Huttl (1948); Hardy and D'Appolonia (1946); Corps of Engineers (1946, 1945); Zhukov (1946); Muller (1945); Richardson (1944); and others. Refinements of the techniques and data on Alaskan research projects (Wilson, 1948; Jaillite, 1947; Barnes, 1946) are contained largely in unpublished reports of various federal agencies.

Eager and Pryor (1945) have shown that road icings (pl. 10, fig. 3) are more common in areas of permafrost than elsewhere. They, Tchekotillo (1946), and Taber (1943b) discuss the phenomena of icings, classify them, and describe various methods used to prevent or alleviate icing.

One of the major factors to consider in permafrost is its water content. Methods of predicting by moisture diagrams (epures) the amount of settling of buildings on thawing permafrost are presented by Fedosov (1942). Anderson (1942) describes soil moisture conditions and methods of measuring the temperature at which soil moisture freezes.

Emphasis should be placed again on the fact that permafrost is a temperature phenomenon that occurs naturally in the earth. If man disturbs the thermal regime knowingly or unknowingly, he must suffer the consequences. Every effort should be made to control the thermal

regime, to promote pergelation or depergelation as desired. Generally the former is difficult near the southern margin of permafrost. If the existing climate is not cold enough to insure that the permafrost remain frozen, serious consideration should be given to artificial freezing in those places where permafrost must be utilized as a construction material. Techniques that were used at Grand Coulee Dam (Legget, 1939) or on Hess Creek (Huttl, 1948) can be modified to fit the situation. It should be borne in mind that the refrigerating equipment need be run only for a matter of hours during the summer after the ground has been refrozen and vegetation or other means of natural insulation have been employed. Bad slides on roads and railroads, settling under expensive buildings, loosening of the foundations of dams, bridges, towers, and the like probably can be treated by re-freezing artificially at less cost than by any other method. In fact the day is probably not far off when airfields of Pycrete (Perutz, 1948) or similar material will be built in the Arctic where no construction materials are available.

Where seasonal frost (active layer) is involved in construction, the engineer is referred to the annotated bibliography of the Highway Research Board (1948) and to such reports as that of the Corps of Engineers (1945, 1946, 1947).

Water supply.—Throughout permafrost areas one of the major problems is a satisfactory source of large amounts of water. Problems encountered in keeping the water liquid during storage and distribution or in its purification are beyond the scope of this report. Small amounts of water can be obtained generally from melted ice or snow. However, a large, satisfactory, annual water supply in areas of continuous permafrost is to be found only in deep lakes or large rivers that do not freeze to the bottom. Even then the water tends to have considerable mineral hardness and organic content. It is generally not economical to drill through 1,000 to 2,000 feet of permafrost to tap ground-water reservoirs beneath, although artesian supplies have been obtained under 700 feet of permafrost (Dementiev and Tumel, 1946) and under 1,500 feet of permafrost (Obruchev, 1946).

In areas of discontinuous permafrost, large annual ground-water supplies are more common either in perched zones on top of permafrost or in nonfrozen zones within or below the permafrost (Cederstrom, 1948; Péwé, 1948b).

Annual water supply in areas of sporadic permafrost normally is a problem only to individual householders and presents only a little more difficulty than finding water in comparable areas in temperate zones.

Surface water as an alternate to ground water can be retained by earthen dams in areas of permafrost (Huttl, 1948).

Throughout the Arctic, however, the quality of water is commonly poorer than in temperate regions. Hardness, principally in the form of calcium and magnesium carbonate and iron or manganese, is common. Organic impurities and sulfur are abundant. In many places ground water and surface water have been polluted by man or organisms.

Muller (1945) presents a detailed discussion of sources of water and the engineering problems in permafrost areas of distributing the water. Joestings (1941) describes a partially successful method of locating water-bearing formations in permafrost with resistivity methods.

Sewage disposal.—Sewage disposal for large camps in areas of continuous permafrost is a most difficult problem. Wastes should be dumped into the sea, as no safe place exists on the land for their disposal in a raw state. As chemical reaction is retarded by cold temperatures, natural decomposition and purification through aeration do not take place readily. Large streams that have some water in them the year around are few and should not be contaminated. Promiscuous dumping of sewage will lead within a few years to serious pollution of the few deep lakes and other areas of annual surface-water supply. Burning is costly. As yet no really satisfactory solution is known to the writer. In discontinuous and sporadic permafrost zones, streams are larger and can handle sewage more easily, yet even there sewage disposal still remains in places one of the most important problems.

Agriculture.—Permafrost as a cold reserve has a deleterious effect on the growth of plants. However, as an impervious horizon it tends to keep precipitation in the upper soil horizons, and in thawing provides water from melting ground ice. Both deleterious and beneficial effects are negligible after 1 or 2 years of cultivation, as the permafrost table thaws, in that length of time, beyond the reach of roots of most annual plants (Gasser, 1948).

Farming in permafrost areas that have much ground ice, however, can lead to a considerable loss in time and money. Sub-Arctic farming can be done only where a sufficient growing season is available for plants to mature in the short summers. Such areas are in the discontinuous or sporadic zones of permafrost. If the land is cleared of its natural insulating cover of vegetation, the permafrost thaws. Over a period of 2 to 3 years, large cave-in lakes have developed in Siberia (I. V. Poiré, oral communication), and pits and mounds have formed in Alaska (pl. 10, fig. 4) (Péwé, 1948a, 1949; Rockie, 1942). The best solution is to select farm lands in those areas free of permafrost or free of large ground-ice masses (Tziplénkin, 1944).

Mining.—In Alaska, placer miners particularly, and lode miners to a lesser extent, have utilized permafrost or destroyed it as neces-

sary since it was first encountered. Particularly in placer mining, frozen ground has been the factor that has made many operations uneconomical (Wimmeler, 1927).

In the early part of the century, when gold was being mined so profitably at Dawson, Fairbanks, Nome, and other places in northern North America, it was common for miners to sink shafts more than 100 feet through frozen muck to the gold-bearing gravels (P. S. Smith, unpublished manuscript). These shafts were sunk by steam jetting or by thawing with fires or hot rocks. If the muck around the shafts or over the gravels thawed, the mines had to be abandoned.

Now, with the advent of dredges, such ground is thawed, generally with cold water, one or more years in advance of operations. In the technique used holes are drilled in or through the permafrost at regular intervals of possibly 10 to 30 feet, depending on the depth and types of material, and cold water is forced through the permafrost into underlying permeable foundations or out to the surface through other holes. Hot water and steam, formerly used, are uneconomical and inefficient. Where thick deposits of overburden cover placers, they are removed commonly by hydraulicking. Summer thaw facilitates the process (Patty, 1945).

Permafrost is commonly welcomed by the miners in lode mining, as it means dry working conditions. Its effect on mining operations other than maintaining cold temperatures in the mine is negligible unless it contains aquifers. Because of cold temperatures, sealing such aquifers with cement is difficult, and other techniques must be used as the situation demands.

Some well drilling in permafrost requires modifications of existing techniques and more careful planning for possible exigencies (Fagin, 1947). Difficulty may be encountered in getting proper foundations for the rig. In rotary drilling, difficulty may be experienced in keeping drilling muds at the proper temperature, in finding adequate water supplies, or in finding proper local material for drilling muds. In shallow holes particularly, the tools will "freeze in" after a few hours of idleness. In many places refreezing of permafrost around cased holes produces pressures great enough to collapse most casing. Cementing of casings is costly and very difficult, as ordinary concrete will not set in subfreezing temperatures. Deep wells below the permafrost may encounter high temperatures (100° to 150° F.), and the hot drilling muds on returning to the surface thaw the permafrost around the casing and create a settling hazard in the foundation of the rig and also a disposal problem. In some foundations refrigerating equipment must be used to prevent settling.

Permafrost also may act as a trap for oil or even have oil reservoirs within it. The cold temperature adversely affects asphalt-base

types particularly and cuts down yields. Production difficulties and costs go up (Fagin, 1947).

Refrigeration and storage.—Natural cold-storage excavations are used widely in areas of permafrost. They are most satisfactory in continuous or discontinuous zones. Permafrost should not be above 30° F.; if it is, extreme care in ventilation and insulation must be used. Properly constructed and ventilated storerooms will keep meat and other products frozen for years. Detailed plans and characteristics required for different cold-storage rooms are described by Chekotillo (1946).

Trafficability.—In the Arctic and sub-Arctic most travel overland is done in winter, as muskegs, swamps, and hummocky tundra make summer travel exceedingly difficult (Navy Department, 1948-49; Fagin, 1947). Tracked vehicles or sleds are the only practical types. Wheeled vehicles are unsatisfactory, as most of the area is without roads.

Permafrost aids travel when it is within a few inches of the surface. It permits travel of D8 caterpillar tractors and heavier equipment directly on the permafrost. Sleds weighing many tons can be pulled over the permafrost with ease after the vegetal mat has been removed by an angle-bulldozer. Polygonal ground, frost blisters, pingos, and small, deeply incised thaw streams (commonly called "beaded" streams), rivers, and lakes create natural hazards to travel.

In areas of discontinuous and sporadic permafrost, seasonal thaw is commonly 6 to 10 feet deep, and overland travel in summer can be accomplished in many places only with amphibious vehicles such as the weasel or LVT. Foot travel and horse travel are very slow and laborious in many places because of swampy land surfaces and necessity for making numerous detours around sloughs, rivers, and lakes.

Military operations.—Permafrost alters military operations through its effects on construction of airbases, roads, railroads, revetments, buildings, and other engineering projects; through its effects on trafficability, water supply, sewage disposal, excavations, underground storage, camouflage, explosives, planting of mines, and other more indirect ways (Edwards, 1949; Navy Department, 1948-49). Military operations commonly require extreme speed in construction, procuring of water supply, or movement of men and material. Unfortunately it is not always humanly possible to exercise such speed (Fagin, 1947). Large excavations require natural thawing, aided possibly by sprinkling (Huttl, 1948), to proceed ahead of the earth movers. Conversely, seasonal thaw may be so deep as to prevent the movement of heavy equipment over swampy ground until freeze-up. Or, similarly, it may be necessary in a heavy building to steam-jet piles into permafrost and allow them to freeze in place before loading

them. These tasks take time, and proper planning is a prerequisite for efficient operation.

Camouflage is a problem on the tundra. Little relief or change in vegetation is available. Tracks of heavy vehicles or paths stand out in marked contrast for years. It is easy to see in aerial photographs footpaths and dog-sled trails abandoned 10 years or more ago.

Mortar and shell fire, land mines, shaped charges, and other explosives undoubtedly respond to changes in the character of permafrost, but no data are available to the author.

FUTURE RESEARCH NEEDED

Throughout the foregoing pages brief reference is made to aspects of permafrost or effects of permafrost on engineering, geologic, biologic, and other scientific problems for which few factual data are available. However, in the event that the reader has received the impression that a great deal is known of permafrost, it is pointed out that the science of frozen ground is relatively young and immature. It has lacked a coordinated and comprehensive investigation by geologists, engineers, physicists, botanists, climatologists, and other scientists. It is barely in the beginning of the descriptive stages, and only now is it receiving the world-wide attention it deserves.

As our civilization presses northward, the practical needs of construction, water supply, sewage disposal, trafficability, and other engineering problems must be solved speedily and economically. Our present knowledge is relatively meager, and trial-and-error methods are being used much too frequently. Practical laboratory experiments (Taber, 1930a, 1930b) and controlled field experimental stations, such as that at Fairbanks, Alaska (Jaillite, 1947), are needed in various situations in the permafrost areas. From these stations methods and techniques of construction can be standardized and appropriate steps taken to meet a particular situation. Such laboratories must be supplemented with Arctic research stations such as are found in the Soviet Union where more than 30 natural-science laboratories with permanent facilities and year-around basic studies in all phases of Arctic science are going on. The Arctic Research Laboratory at Point Barrow (Shelesnyak, 1948) is a start in the right direction. The academic approach must accompany the practical approach if satisfactory solution of the problem is to be found.

To name all the specific topics for future research would make this paper unduly long, as no phase of permafrost is well known. However, the author reiterates that the problems cannot be solved adequately until the phenomena of heat flow in all natural and artificial materials in the earth are understood and correlated with insolation, atmospheric conditions, geothermal gradients, and the complex sur-

face of the earth. Then, possibly, criteria can be set up to evaluate within practical limits the effect of various structures and materials on the dissipating surface of the earth. The complexities of geology (lithology, structure, and texture of soils and rock), hydrology, vegetation, and climate of the Arctic make the solution a formidable task but the research an intriguing problem for all earth scientists.

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EARTHQUAKES IN NORTH AMERICA¹

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[With 1 plate]

During the past 10 years considerable progress has been made in determining the seismicity in a given area—the frequency of occurrence, and distribution of earthquakes. Earlier investigations were based almost completely on field observations, but now extensive use of instrumental records is possible. This assures much more uniform results for the whole earth. The use of seismograms in investigations of seismicity was made possible by the development of methods which permit a rapid calculation of a function of the earthquake energy from instrumental observations. The first seismogram of a distant earthquake that was recognized as such was made on April 17, 1889, when an instrument at Potsdam wrote a record identified as that of a shock in Japan. (Rebeur-Paschwitz, 1894, p. 436.) During the following years instruments were designed which gave fairly good records of distant earthquakes. In 1897, a committee of the British Association for the Advancement of Science called attention to the desirability of observing earthquake waves that had traveled great distances. By 1899, 13 stations provided such observations and the results were analyzed. In 1904 the number of stations reporting had increased beyond 100, but less than half of them reported wave arrival times reliable within about a quarter-minute. From that time on, however, it has been possible to locate within a few hundred miles all great earthquakes and most major shocks. In 1907 the International Central Station at Strasbourg issued the first catalog giving all readings for the larger shocks reported for 1904. Thus, starting with 1904, research on seismicity could be based on instrumental observations. The systematic publication of such data was discontinued during the First World War (when the catalog for 1908 was in press) and later was resumed, starting with the data for 1918. For the years 1912 to 1917 summaries for selected shocks were published by the British Association for the Advancement of Science under the supervision of H. H. Turner, University Observatory, Oxford.

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Detailed data concerning arrival times of waves at the reporting seismological observatories are printed in the International Seismological Summaries. In addition, these volumes contain calculated values of the coordinates and depths of the earthquake foci and the origin times of the shocks. They were formerly compiled at Oxford, England, and now at Kew (Turner et al., 1923-50). The summaries are based on the bulletins that are issued by most seismological stations. Some of these station bulletins contain, in addition to observed times of various phases, the calculated amplitudes of the ground motion. With this information it is possible to determine the size of the earthquakes. The great importance for research of all such station bulletins and international catalogs is obvious.

There are now roughly 300 seismological stations with accurate time service (at least to the nearest second) practically all over the world, including South Africa, South America, New Zealand, Samoa, Australia, and Madagascar in the Southern Hemisphere, and a much denser network in the Northern Hemisphere.

Until about 10 years ago the size of an earthquake could be estimated only from the observed size of the area of perceptibility or of damage or from changes found at the surface of the earth. Arbitrary scales were applied to such data to find the intensity of a shock. For example, in the scale used in the United States (Wood and Neumann, 1931), intensity II indicates that the shock was felt only by a few persons; intensity V, that it was felt by everyone, many were awakened, some dishes were broken, etc.; intensity VIII indicates slight damage in specially designed structures, considerable damage in ordinary buildings, great damage in poorly built structures; and intensity XII, the maximum, indicates destruction of all structures. A scale of wholly different nature, based on instrumental data, was devised by C. F. Richter (1935). He defined magnitude of an earthquake at average (shallow) depth in southern California as the common logarithm of the maximum trace amplitude expressed in thousandths of a millimeter, with which the standard short period torsion seismometer (period 0.8 second, magnification 2,800, damping nearly critical) would register that earthquake at an epicentral distance of 100 kilometers. Magnitude $M=2$ corresponds in shallow earthquakes to a shock barely felt; a shock of magnitude 5 causes minor damage; magnitude 7 is the lower limit of major earthquakes; $8\frac{1}{2}$ is the highest magnitude that has been determined from amplitude data given in individual bulletins of seismological stations since 1904. This magnitude scale was later extended by Gutenberg and Richter (1936, 1942) to apply to shallow earthquakes occurring in other localities and recorded by other types of instruments. Gutenberg (1945a) devised means for determining magnitudes of shallow earthquakes

using amplitudes and periods of waves that had traveled through the interior of the earth. He also extended the scale to include deep-focus earthquakes (Gutenberg, 1945b). It is now possible to determine the magnitude of larger earthquakes within a few tenths of the scale from seismograms at any well-equipped station. The relationship between magnitude M of an earthquake and its energy E in ergs is given roughly by the approximate equation $\log E = 12 + 1.8M$ (Gutenberg and Richter, 1949). This holds for any focal depth. The data concerning the magnitude and the instrumentally determined epicenters and depths of foci of earthquakes provide the basis for seismicity studies.

Lists of earthquakes and other results of such an investigation of earthquakes recorded over the period from 1904 to 1947 have been published by Gutenberg and Richter (1949). Much of the following information is taken from this book.

The use of magnitudes for the first time provides reliable information concerning the relative seismicity of all regions of the earth. It eliminates the effects of density of population and of communication facilities on the determination of intensities of reported earthquakes, as well as effects of uneven distribution of seismological observatories on seismicity patterns. If the magnitude of the earthquakes is not considered, distorted appearance of seismicity maps may result from an accumulation of many small shocks, which are plotted only in regions well covered by stations with sensitive instruments. Thus, Europe—which, except for the Mediterranean area, has a low actual seismicity—has appeared on maps in the past as a region of relatively high seismic activity. There are now five stations reporting magnitudes of earthquakes in their routine bulletins, but many more regularly furnish amplitude data required for the magnitude determination. Magnitude can be determined from a seismogram at any station where instrumental constants are known and where a clear record of an earthquake has been written, regardless of the distance or depth of the shock. Magnitudes determined at different stations rarely differ by more than 0.3 units from the average for a given earthquake.

The outer part of the earth consists of relatively inactive blocks, separated by active zones falling into four groups: (1) the circum-Pacific zone, which includes about 80 percent of all shocks with origins at a depth not exceeding 60 kilometers (about 40 miles), 90 percent of the so-called intermediate shocks, which have their sources at depths between 60 and 300 kilometers (about 40 and 190 miles), and all deeper shocks (maximum observed depth approximately 400 miles). (2) The Mediterranean and trans-Asiatic zone, which includes nearly all remaining intermediate and large shallow shocks.

(3) Narrow belts of shallow shocks, which follow the principal ridges in the Atlantic, Arctic, and Indian Oceans. (4) Moderate activity associated with rift structures such as those of East Africa and the Hawaiian Islands.

The most extensive inactive block is the Pacific basin (excluding the Hawaiian Islands). On the continents, most of the ancient shields are quite inactive. Between the stable shields and the active belts are regions of minor to moderate activity having occasional large shocks. Small shocks (magnitude 5 and less) apparently occur everywhere.

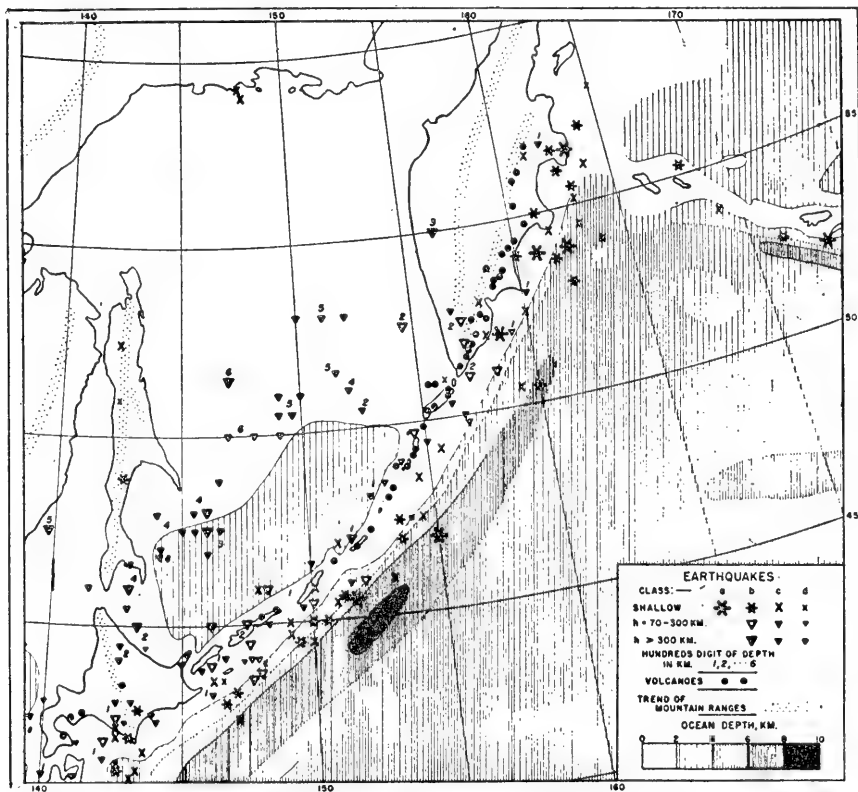


FIGURE 1.—The structural arc from northern Japan to Kamchatka. (After Gutenberg and Richter, 1949.) (See also fig. 2.)

A structural arc of the Pacific region—for example the Tonga arc, the Marianas arc, or the northern Japan arc (figs. 1 and 2)—exhibits the following typical features in order, beginning at the convex side: (A) a foredeep; (B) shallow earthquakes and negative gravity anomalies along anticlines; (C) positive gravity anomalies and slightly deeper shocks; (D) the principal mountain arc (Tertiary or older), with active volcanoes and shocks about 100 kilometers deep; (E) an older structural arc with volcanism in a late stage or

extinct, and shocks about 200 to 300 kilometers deep; (F) a belt of deep shocks (below 300 kilometers). In some arcs only a few of these features can be identified; this is true of the similar structural arcs along the southern Alpid front of the trans-Asiatic zone. In parts of the Pacific belt (for example, along the coast of the continental United States (fig. 3) and British Columbia) structural arcs and the accompanying features are absent. In many such sectors (as in California) there is strong evidence of block faulting in place of the folding characteristic of the arcs.

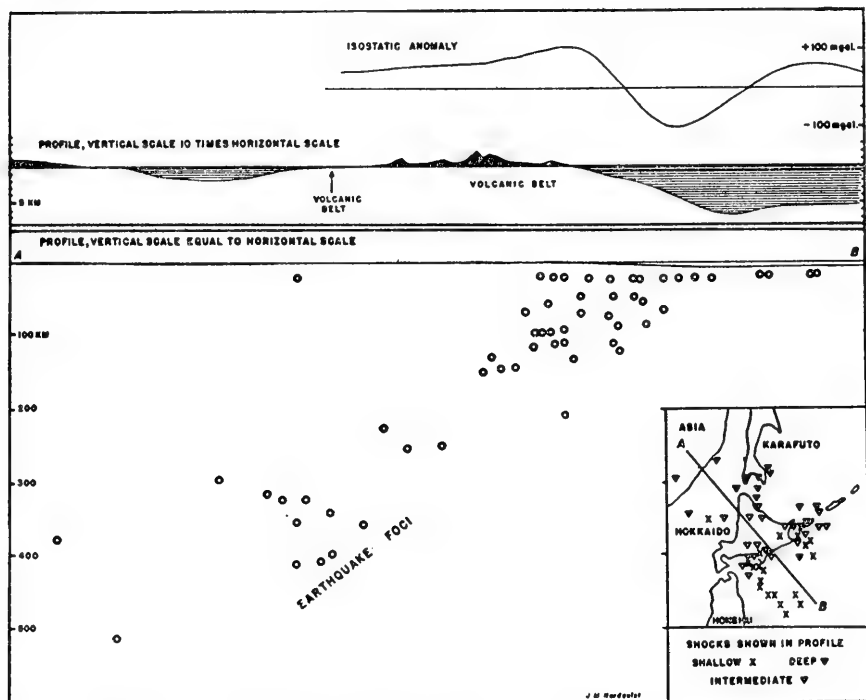


FIGURE 2.—The structural arc in northern Japan. (After Gutenberg and Richter, 1949.) (See also fig. 1.)

The seismicity of North America is mainly associated with the Pacific belt. Relatively high activity occurs in the area of the Aleutian Islands. The Aleutian arc is a typical Pacific arc; it extends from the Commander Islands into central Alaska. Seismic and volcanic activity is relatively high. In general, shallow seismic activity follows the northern concave side of the Aleutian trench. Intermediate shocks at depths down to about 100 miles occur along the north side of the island arc. No shocks originating deeper than 20 miles are known in the area of the North American Continent. The shocks having depths of approximately 60 miles occur near the line of volcanoes, as

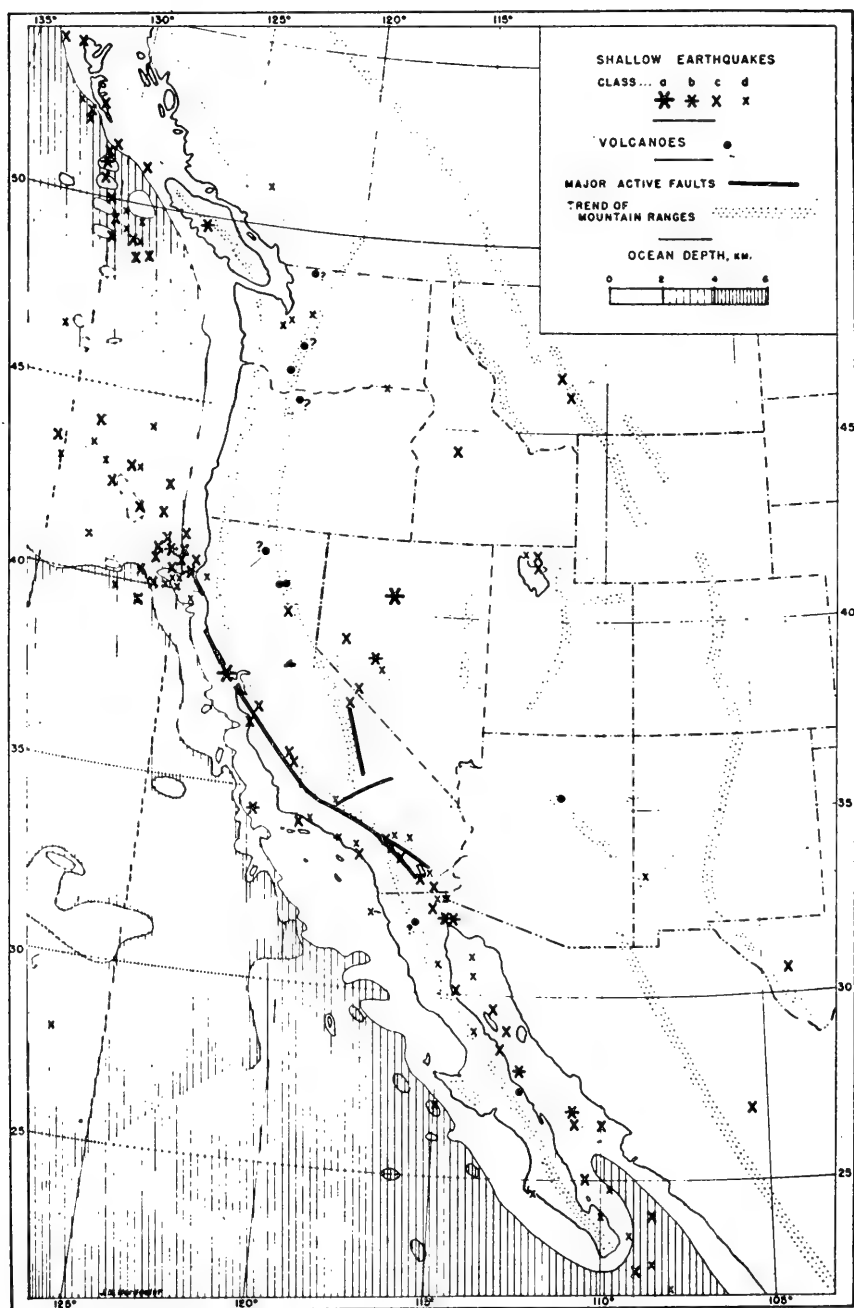


FIGURE 3.—Epicenters of larger earthquakes in British Columbia, the western United States, and northwestern Mexico between 1905 and 1947. (After Gutenberg and Richter, 1949.)

usual. Shallow shocks in the interior of Alaska represent an interior structure.

Another sector of the Pacific belt extends from southeastern Alaska to Puget Sound and includes the rather active area of the Queen Charlotte Islands (fig. 3, upper left), where a great earthquake occurred in August 1949. There are neither well-developed ocean deeps nor shocks at intermediate or greater depth in this area. The seismic activity decreases considerably in the vicinity of the State of Washington. There is a clear gap between this and the next seismic zone, which begins about 200 miles off the coast of Oregon. Thence, an uninterrupted belt of earthquake foci extends in a southeasterly direction (fig. 3). It reaches the coast of northern California, then follows the coastal area to the region of San Francisco and continues inland following the well-known San Andreas fault zone. This zone has been traced at the surface as far south as the Salton Sea, but the earthquake belt continues along the Gulf of California at least as far as the southern tip of Lower California. Volcanic activity is low along this zone; the few volcanoes, such as Mount Lassen, and Tres Virgenes in Lower California, appear to be in a late state of activity.

The next sector to the southeast is one of noticeably higher activity. It follows the Pacific coast from Colima in Mexico to Panama. There are two lines of active volcanoes, one extending west-east across central Mexico from Colima to Veracruz, the other beginning in Guatemala and extending southeastward through Central America. Accompanying the line of active volcanoes, once more earthquakes are found at depths of somewhat less than 100 miles. Mexico City is in the west-east belt of intermediate shocks and consequently experiences rather frequent earthquakes; however, they usually cause relatively little damage as a result of their considerable depth below the surface. Ocean deeps off the Mexican coast are well developed and include the Acapulco deep and the Guatemala trench. Unfortunately, gravity measurements are very scarce off the whole Pacific coast of North America but the few data available indicate appreciable negative gravity anomalies, at least off the coast of Mexico in the neighborhood of the ocean deeps.

The earthquake belts mentioned thus far are responsible for most of the seismic activity in North America. In the United States, for example, the California-Nevada region contains about 90 percent of the whole seismic activity. This result is based mainly on instrumental data covering the past 40 years, but is in good agreement with historical information (Gutenberg and Richter, 1944). The remaining shocks are partly situated in areas marginal to stable masses, partly in regions which have undergone higher tectonic activity in the not too distant geological past. The Rocky Mountains and related structures, which

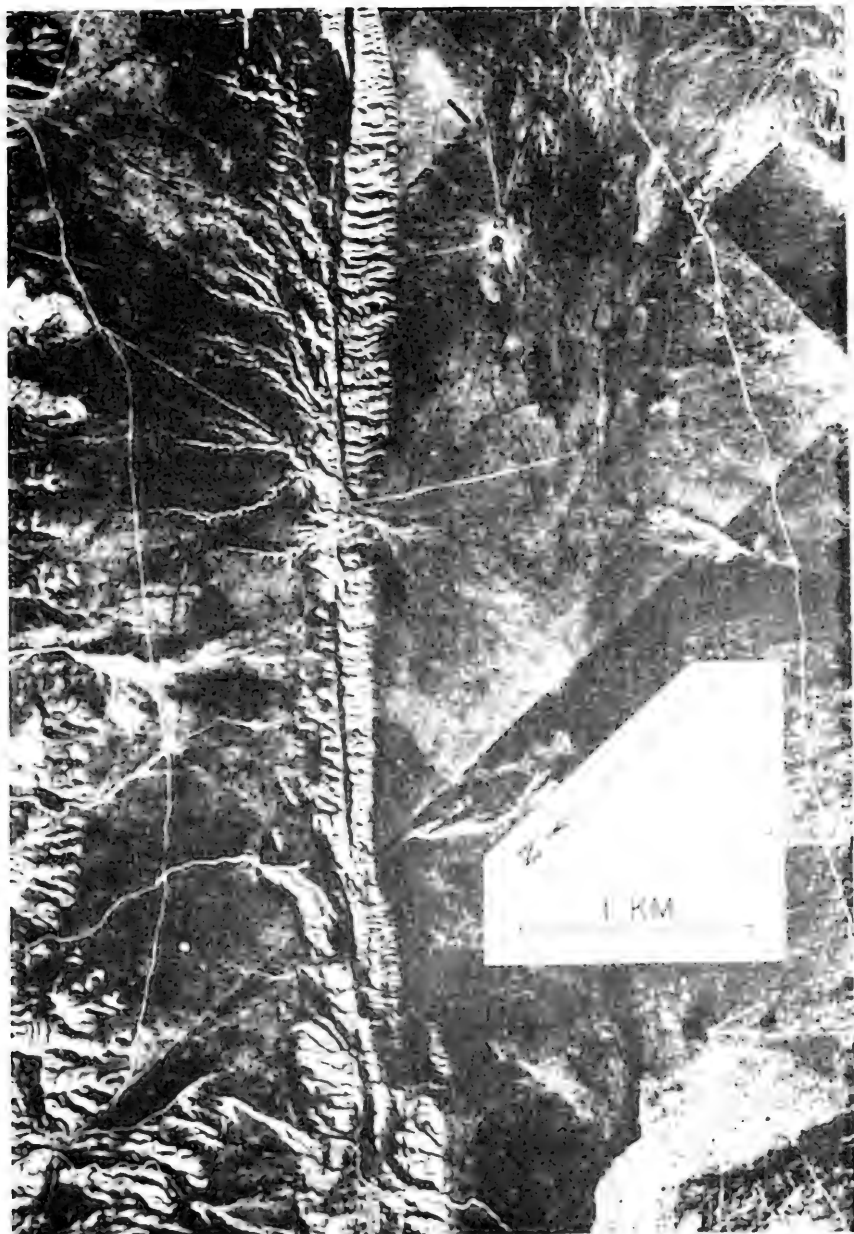
are of the same age as others belonging to the circum-Pacific belt, show relatively low seismicity.

Other regions with occasional earthquakes include the area between Siberia and Alaska. This is transgressed by the Bering Sea, whose coasts are probably of structural significance, since practically all the known shocks of the regions are close to them. Activity marginal to the Canadian shield includes a major earthquake off Newfoundland in 1929; to the northeast, marginal shocks have occurred in Davis Strait and Baffin Bay. There is notable activity along the St. Lawrence River.

The Appalachian belt is a region of fairly frequent minor activity. The northern part of it is shaken occasionally by marginal shocks of the Canadian shield, and some moderate earthquakes originate within the Appalachian area. Near the Atlantic coast is the epicenter of the Charleston (S. C.) earthquake of 1886. Historically the greatest shocks in the United States outside the Pacific area are the earthquakes of 1811 and 1812 in the Mississippi Valley, which originated near New Madrid (Mo.); their magnitudes possibly surpassed magnitude 8. It is of interest to note that shocks east of the Rocky Mountains seem to originate occasionally at depths of about 30 or 40 miles below the surface, which is near the lower limit of "shallow" earthquakes. As a consequence, these shocks are sometimes felt over a wide area without doing any serious damage anywhere. An earthquake near Charleston (Mo.) in 1895 occasioned only minor damage near its epicenter and yet was felt from the District of Columbia to New Mexico, from Canada to Louisiana. Contrasting with these shocks, California earthquakes usually originate at a depth of approximately 10 miles; even when they cause considerable damage, they have much smaller areas of perceptibility.

The instrumental data furnish information as to the contemporary seismicity of any given region. However, the historic records where available indicate that in most areas the seismicity changes only relatively little with time; on the other hand, a few regions are known to have shown a much higher seismic activity in earlier periods, and in some instances major earthquakes have occurred in regions which have been considered inactive. Of the roughly one million earthquakes per year which are potentially strong enough to be felt somewhere on earth (magnitude 2 and more) about 2 percent occur in the earthquake belt of California and Nevada (including the shocks off the coast of northern California and Oregon). For details see Gutenberg and Richter (1949).

It is possible to make certain statistical statements about the frequency and the probability of the occurrence of earthquakes within relatively large areas over long periods of time. For example, of the present average of about 220 great shocks ($M \geq 7\frac{3}{4}$) and about 1,200



OFFSETS OF STREAMS ALONG THE SAN ANDREAS FAULT AT THE CARRIZO PLAIN, CALIF. (ABOUT $119\frac{1}{2}^{\circ}$ W., 35° N.)

Directions of the streams from left to right. (Taken by the Fairchild Aerial Survey, Los Angeles, for the Barnsdall Oil Co., in February 1936.)

additional major earthquakes ($M=7.0-7.7$) per century over the whole earth, about 5 and 18 respectively can be expected to occur in the Pacific United States, about 14 great shocks and 65 major shocks in Alaska and the Aleutian Islands, and about 11 major shocks in the remainder of central, eastern, and northern North America. It is not possible, however, to predict the approximate location or time of larger earthquakes, since too little information is available on the sources of energy and the processes involved in the building up of strain leading to an earthquake.

Some information on tectonic processes is being furnished by geodetic measurements. The United States Coast and Geodetic Survey has installed a special system of triangulation stations and bench marks in California, which are checked from time to time. In this way, changes in elevation as well as horizontal movements over larger areas are found. Such measurements have indicated, for example, that during the past 60 years the region on the west side of the San Andreas fault between San Francisco and San Jose has moved roughly 10 feet north relative to the east side (Whitten, 1948). This is not a new type of movement; geological evidence indicates that this type of movement has persisted during many centuries, at least. Wherever rivers flow across the fault system the river bed has been displaced in the same direction—the western side northward relative to the eastern side. The total amount of these displacements is not known. In the neighborhood of the San Andreas fault (pl. 1) some offsets exceed 1 mile; however, no information concerning displacements in excess of the distances between successive valleys can be found in this way. Thus far no definite correlation has been found between rocks corresponding to each other on the two sides of the San Andreas fault.

Records of earthquakes have been used to find the direction of the movement at the source and to draw conclusions as to the fault movement during a shock. It is possible to determine whether the first motion of the longitudinal waves is from the source toward the station or in the opposite direction. Thus, for example, earthquakes along the San Andreas fault to the north of Pasadena begin on the Pasadena records with a dilatation toward the source, whereas earthquakes from the San Andreas fault to the east of Pasadena start with a compression toward Pasadena (Gutenberg, 1941). The motion in the shear waves can be investigated in a similar way. Studies of this type, which have been undertaken in California during recent years, have fully confirmed the persistence of the movements just described (Dehlinger, 1950). They throw some light on the details of the processes in earthquakes.

It is of interest that similar investigations seem to indicate that

in Japan, in the Philippines, and in New Zealand the prevailing movement is such that the continental side is also moving southward relative to the Pacific side. However, the data are insufficient for a more general conclusion as to movements of the continents relative to the Pacific block.

Additional information on processes leading to earthquakes can be expected from investigations on the relation of earthquakes and aftershock sequences (fig. 4) to rock creep, which Hugo Benioff is

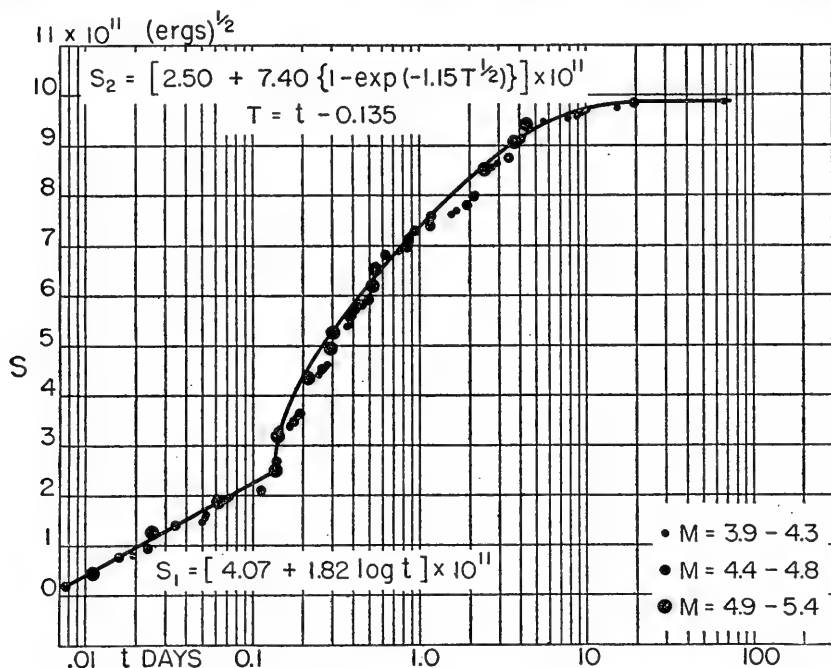


FIGURE 4.—Strain release characteristic, Long Beach aftershock sequence, 1933. (After H. Benioff, 1951a.)

undertaking (Benioff, 1949, 1951a). On the basis of the elastic rebound theory, the fault rock strain relief which produces an earthquake is proportional to the square root of the energy. Consequently, in a sequence derived from a single fault system the square root of the energy of each shock represents a strain release (or increase) increment, and a plot of the accumulated sum of such increments against time represents the motion of a fault as a function of time (fig. 5). The method thus appears to provide a means for observing tectonic movements in progress. The energy is derived from magnitudes of earthquakes as determined by Gutenberg and Richter (1949). In the case of aftershock sequences, Dr. Benioff has found that creep curves exhibit either simple compressional elastic creep of the fault rock or compressional elastic creep release followed by shearing elastic creep release.

Study of a number of earthquake sequences occurring in all the active regions of the world has revealed that most of them form creep series. Many types of creep are represented, such as constant velocity creep, exponential velocity creep, elastic creep, and elastic flow creep. Individual sequences may have linear extents of 20° to 30° of latitude, as in the case of the South American and Tonga sequence, and the evidence strongly suggests that they are derived from movements of single mechanical units. The deep-focus Tonga sequence exhibits

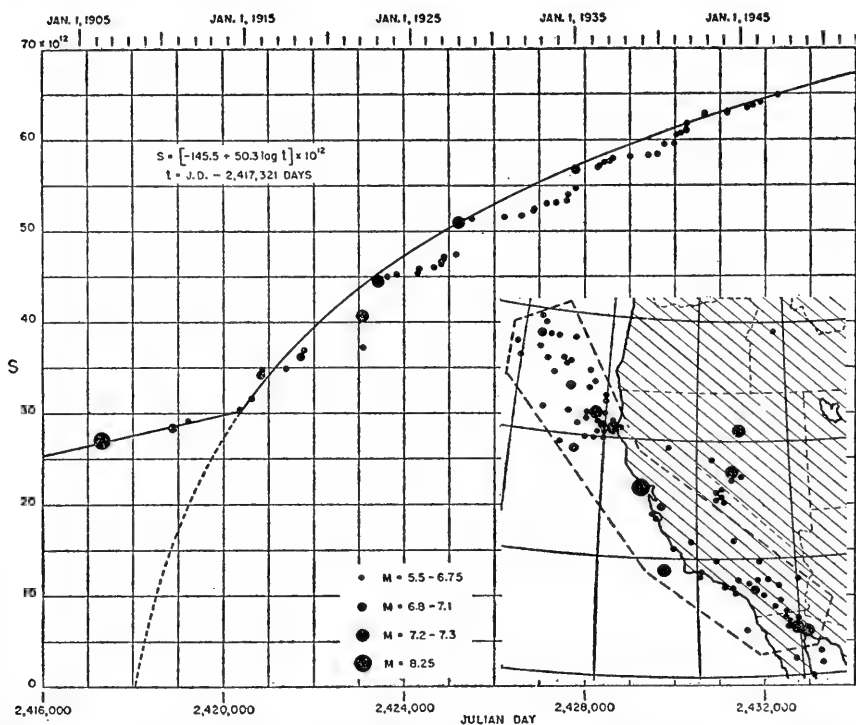


FIGURE 5.—Strain release characteristic, San Andreas fault system (as indicated in the inserted map). Symbols for magnitude refer to the main figure only. (After H. Benioff, unpublished.)

elastic creep which continued some 25 years, thus demonstrating that at depths of 650 kilometers rock masses can support elastic creep stresses without appreciable flow for many years. Unfortunately, data available for this type of research cover too short a period to permit conclusions to be drawn as to the exact processes involved. In some of the series investigated by Dr. Benioff, discontinuities in the rate of movement were observed within the short interval of time during which instrumental records are available. Other sequences appear to exhibit no evidence of a discontinuous change in rate since 1904.

Dr. Benioff (1951b) has found, in addition, that the accumulated strain-rebound characteristic of all world earthquakes of magnitudes 8.0 to 8.6 that have occurred since 1904 exhibits a saw-tooth shape with very nearly linear segments. The serrations decrease regularly with time in amplitude as well as in period. If a proposed interpretation is correct, the curve indicates the following conclusions: (1) World earthquakes in this magnitude range are not independent events. They are related in some form of world-wide stress system. (2) From 1908 to 1950 the total secular strain accumulated at a remarkably constant rate. (3) This strain was released in five active periods of decreasing lengths separated by quiescent intervals of very small or no activity. (4) During the active periods the strain release proceeded at approximately twice the rate of the secular strain accumulation.

Still another type of approach could start with stresses to be expected from theoretically derived forces—such as those connected with contraction or expansion of the earth, or subcrustal currents—and their effect on geological structures. All ideas dealing with forces and structures are by far too controversial to permit the drawing of conclusions concerning expected seismicity, but data obtained from earthquakes and artificial explosions are at present the most reliable basis for hypotheses connected with tectonic and structural problems. The distribution of earthquakes and the other observed phenomena in the Pacific arc structures leave little doubt that there is a great difference between the structure of the Pacific crustal layers and the structure of crustal layers in the continents and in the Atlantic.

A change in surface structure occurs at some point off all Pacific coasts. In the western and southwestern Pacific the boundary is given by the so-called Marshall line or andesite line, which separates the more andesitic material on the continental side from the less andesitic on the Pacific side. This line is known to run to the east of the Japanese, Marianas, and Philippine Islands and crosses the Caroline Islands leaving Yap and Palau on the continental side. It turns sharply to the east near the northwestern end of New Guinea and later passes between Samoa (which is on the Pacific side) and the Tonga Islands (on the continental side). Near Samoa it turns southward and remains to the east of the Kermadec Islands and of New Zealand. Its location in the eastern Pacific is not known, since no islands can be used there for locating the line, but it appears to follow along the coast of North America at a distance which varies from place to place. The andesite line is the intersection of a deep-going surface of discontinuity with the surface of the earth. The difference in structure on its two sides provides one of the reasons for the accumulation of earthquakes along the line. The fact that in many areas a belt of large negative gravity anomalies parallels the

andesite line indicates tectonic processes extending to rather large depth. The deep-focus earthquakes are connected with these processes, and the fact that the very deep shocks occur nowhere on earth except near and inland of the andesite line is another indication of the unique structure of the Pacific basin.

All information available for the Atlantic side of North America indicates that the transition from the continent to the bottom of the Atlantic is rather gradual. Although granitic material is probably missing in the deeper parts of the Atlantic basin, as shown by recent seismic explorations by W. Maurice Ewing and his collaborators, deeper continental material may be present throughout the bottom of the Atlantic Ocean (Ewing et al., 1937, 1950). In contrast with the Pacific coasts, there are no earthquake belts surrounding the Atlantic or the Indian Ocean. However, earthquakes and volcanoes occur along the mid-Atlantic ridge. In contrast with this ridge and similar ridges with seismic activity in the Indian Ocean, no ridges of the Pacific show any earthquake activity, with the exception of the area near the Hawaiian Islands.

There is no agreement on any hypothesis as to the ultimate source that furnishes the energy for earthquakes. Perhaps they are connected with differences in heat production in the various units of the earth's crust. Laboratory experiments indicate that much more radioactive heat is generated in granitic material than in the more basic material (simatic rocks) of the deeper layers and much less in the ultrabasic material which probably extends relatively close to the surface in the Pacific area. There is, in addition, the effect of the temperature difference between ocean bottom (which is kept at a temperature near 0° C. by the deep water in the oceans) and the temperature of roughly 200° C. at the corresponding depth under the continents. Subcrustal currents may be a consequence of this horizontal temperature gradient. This may be combined with the fact that the structural arcs along the Pacific boundary are usually interpreted as due to forces either pushing or drawing subcrustal material downward toward the foredeeps, with compensating movements elsewhere. However, we know too little about the details of these processes.

During recent years it has been a very common experience in geophysics that hypotheses concerning the structure and the processes in the earth's crust have become less and less certain as data accumulate; frequently the fact is revealed that the approximations used were not as good as was believed. There is little doubt that the number of recognized unsolved problems is increasing rather than decreasing in practically all fields of geophysics. The hope of explaining and predicting earthquakes seems to be more remote now than at any previous time.

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WOLF CREEK METEORITE CRATER, WESTERN AUSTRALIA¹

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[With 2 plates]

INTRODUCTION

The Wolf Creek meteorite crater, situated in the Kimberley District of Western Australia, is the second largest crater of meteoritic origin to be discovered on the earth's surface.² The crater has been named by Dr. Reeves (Reeves and Chalmers, 1948) after the adjacent watercourse, Wolf Creek.

The nature of the crater was first recognized on June 21, 1947, by Dr. Frank Reeves and N. B. Sauve, of the Vacuum Oil Co., during an aerial reconnaissance of the Desert Basin in a Zinc Corp. aircraft piloted by Dudley Hart. It was reached on the ground on August 24, 1947, by Reeves, Harry Evans, and Dudley Hart.

The crater was independently located and its meteoritic origin suspected by the writers early in 1948 when preparing a photogeological map from photographs covering the area.

LOCATION AND DESCRIPTION

The crater is situated on the northern edge of the Desert Basin at approximately longitude 127°46' E., latitude 19°18' S., 65 miles south of Halls Creek, the nearest township and aerodrome.

The crater may be reached without difficulty during the dry season by taking the track from Halls Creek to Ruby Plains homestead and thence to Beaudesert Well. Near Beaudesert Well a branch track is followed along the west bank of Wolf Creek as far as the crater (fig. 1).

The crater is situated in an area covered with loose sand with occasional low dunes and sparse vegetation, a few miles south of the last

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²The recent discovery of the gigantic Chubb crater in northwestern Quebec, Canada, makes the Wolf Creek crater the third largest meteorite crater known. An account of a recent expedition to the Chubb crater has been published by V. M. Keen, *Journ. Roy. Astronomical Soc. Canada*, vol. 44, No. 5, pp. 169-180, 1950.—EDITOR.

The Nullagine sediments examined to the north of the crater are gently folded and faulted on a small scale. It seems reasonable to postulate that the general outward dip of the beds forming the wall of the crater is due almost entirely to movement resulting from the explosion of the meteor.

Similar structure has been established in the cases of the Meteor crater of Coconino County, Ariz. (Barringer, 1909), and Texas crater in Ector County, Tex. (Barringer, 1909). It is likely that the bending described from the north wall of the crater is at least partly a structure of premeteor age, as it would appear impossible for surface beds of hard quartzite to bend in such a way without considerably more fracturing.

An examination of the crater both on the ground and from aerial photographs (pl. 2) gives the impression that a greater volume of fractured rock has been piled around the southwest portion of the crater than around other portions, suggesting that the meteor was moving in an arc from the northeast toward the southwest when it struck the ground.

From a study of craters on the earth's surface and on the moon, Dietz (1946) and others have suggested that the radial symmetry and circularity of craters such as the Meteor crater and those on the moon's surface are due to exploding meteors. Explosion craters, in contrast to percussion craters, have circular shape and well-developed radial symmetry regardless of the angle of incidence (fig. 3).

No silica glass or sintered rock has been discovered in the area, but there is every probability that further work will disclose the presence of material of this character.

TABLE 1.—*Analysis*

	Percent	
	A	B
Nickel, Ni in metallic portion.....	3. 71	-----
Nickel, Ni total.....	3. 57	4. 47
Specific gravity.....	3. 42	3. 80

Fragments of various size of heavy metallic material were found around the rim of the crater, particularly along the southern sector. R. O. Chalmers, curator of minerals of the Australian Museum, has advised that "the specimen contains 1.9 percent of NiO, which is far in excess of what would be expected in terrestrial rock."

Samples of meteoritic iron were submitted to the Western Australian Government Chemical Laboratories. The following information is taken from their report. The samples consisted of two fragments,

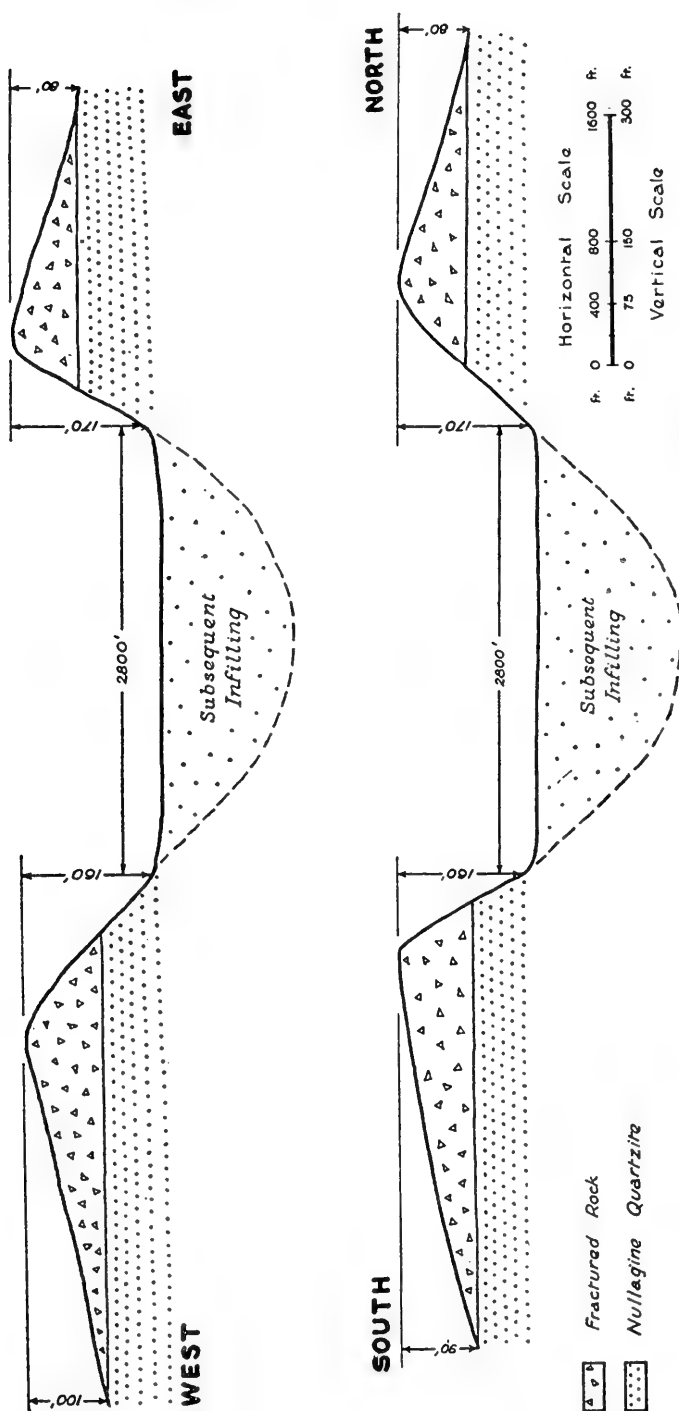


FIGURE 2.—Cross sections of Wolf Creek meteorite crater.

A and B. A weighed approximately 300 grams and B approximately 500 grams. The material is sufficiently magnetic that fragments of pea size may be lifted by a bar magnet, and it consists mainly of iron oxides, hydrated in part, with some silicate minerals too highly impregnated with iron oxides to be identifiable, and a little chalcedony. After fine grinding, specimen A yielded a very small amount (0.06 percent) of metallic iron which was retained on a 90-mesh screen.

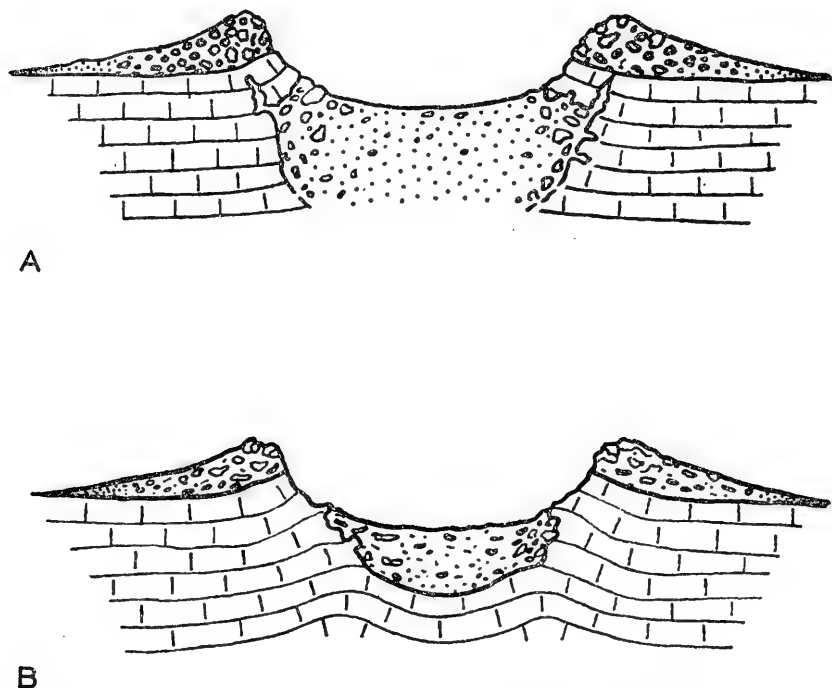


FIGURE 3.—Diagrammatic sections of a typical meteorite crater. A, fracturing and tilting of strata by outward explosion; B, ring anticline by percussion. (After L. J. Spencer.)

GENERAL DISCUSSION

An interesting paper by Nininger (1948) covers the geological significance of meteorites. It took scientists many years to accept the fact that matter from outside the earth and its atmosphere was falling and had fallen on the earth's surface. Today there are still some who will not accept the meteoritic origin of some craters.

It is apparent that studies of craters such as the Meteor crater, Arizona (Barringer, 1909, 1915, 1925), Boxhole crater, Central Australia (Madigan, 1937), Texas crater (Sellards, 1927; Barringer, 1929), Henbury craters (Alderman, 1932), Wabar craters (Philby, 1933), Campo del Cielo craters (Nagera, 1926), Siberian craters

(Whipple, 1930), and now the Wolf Creek crater in Australia have produced an overwhelming amount of evidence in favor of this meteoritic origin. The Wolf Creek crater gives further support to the theory of Dietz (1946) and others who postulate a meteoritic origin for craters on the moon's surface.

From the available literature it appears that seven craters or groups of craters of meteoritic origin have been described (Spencer, 1933). Ashanti crater, occupied by Lake Bosumtwi, Ashanti (Maclaren, 1931), and a group of craters in Estonia³ (Reinwaldt and Luha, 1928; Kraus, Meyer, and Wegener, 1928) remain doubtful. Nininger (1948) also mentions that, in addition to the fall of meteors in Siberia in 1908, "now comes word that a similar, though smaller collision has occurred at a point some 200 miles north of Vladivostock."

Table 2, which gives the dimensions of craters of proved meteoritic origin, is of some interest. The variations in the ratios of width to depth may be explained by either erosion and sedimentation or by an initial accumulation of shattered rock or both. The figure given for the depth of the Wolf Creek crater will be increased when the actual depth to bed rock is investigated.

TABLE 2.—*Dimensions of craters of known meteoritic origin*

Crater	Width (feet)	Depth (feet)	Ratio of width to depth
Meteor crater, U. S. A.-----	3, 900	570	6. 8
Wolf Creek crater, Australia-----	2, 800	170	16. 5
Boxhole crater, Australia-----	575	52	11. 1
Texas crater, U. S. A.-----	530	18	29. 4
Henbury crater, Australia-----	360	60	6. 0
Do-----	240	25	9. 6
Do-----	30	3	10. 0
Wabar craters, Arabia-----	328	40	8. 0
Campo del Cielo crater, Argentina-----	183	16	11. 4
Siberian crater, U. S. S. R.-----	164	13	12. 5

AGE OF THE CRATER

Unfortunately, the youngest sediments in the area occupied by the crater are pre-Cambrian in age.

During the examination of the crater a few loose pieces of pisolitic ironstone or laterite were noticed among the fractured blocks forming the rim of the crater on the eastern side. As one descends the wall of the crater, the layer of laterite, from which the loose pieces were derived, may be seen in situ in the wall.

This is evidence that the meteor struck the ground and exploded after the laterite layer had been formed. Information that has been

³ It is understood that definite evidence of the meteoric origin of the craters in Estonia has since been found.

accumulating over the past few years favors late Miocene as the age of the laterite in northern Australia. It is, therefore, fairly certain that the Wolf Creek crater was formed later than Miocene times.

The erosion of the crater is slight, and signs of erosion on the steep walls of the crater are not well marked. As far as could be ascertained, aboriginals in the area have no record of the meteor in their legends but are aware of the crater.

The evidence suggests, therefore, a Pleistocene or Recent age for the crater.

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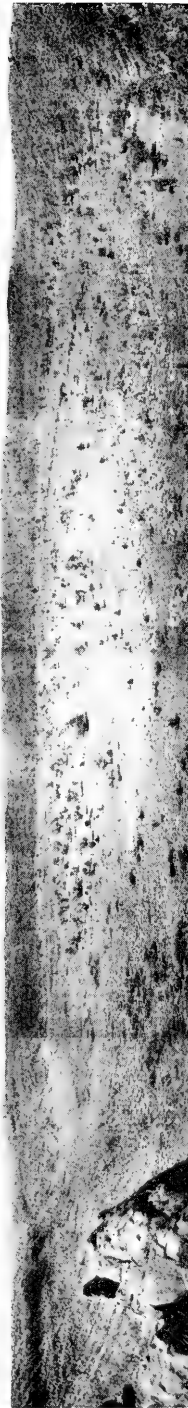
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INTERIOR OF WOLF CREEK METEORITE CRATER, LOOKING SOUTH



AERIAL PHOTOGRAPH OF WOLF CREEK METEORITE CRATER
R. A. A. F. official photograph.

NATURAL HISTORY IN ICELAND¹

By JULIAN HUXLEY, F. R. S.

In Iceland, in the summer of 1949, a number of new facts and experiences, interesting and exciting to a naturalist, came my way—some of them through my own eyes, others through the mouths of the able Icelandic zoologists who put so much of their time and knowledge at the disposition of James Fisher and myself.

Thus we saw various species that were new to us, and sometimes spectacular to look at, like the harlequin duck. That was exciting enough; but the interest was multiplied when we remembered that it is an essentially North American bird, one of the rarest stragglers to Europe, and yet here breeding close to familiar British ducks like mallard, tufted duck, widgeon, and pintail. We found a meadow pipit breeding in a wood, like a tree pipit, instead of on the customary open heath; and what is more, singing a song halfway to a tree pipit's.

We saw some local birds recognizably different from their British congeners, like the Iceland redshank, which is several shades darker than ours. We saw a painted lady butterfly in the northern half of the island—a truly astonishing sight, since its nearest permanent breeding place is the south of France. We got evidence, from our own counts, of the increase of the gannet; and from our Icelandic colleagues of the fact that not only it but 9 or 10 other birds have been rapidly extending their range northward during recent decades.

But the modern naturalist is not content unless he can relate his facts, however valuable, and his isolated experiences, however exciting, to general principles; and the very vividness and novelty of the impressions made by an unfamiliar country will set his scientific imagination to work. Here is the result of my own case—some of the ways in which Iceland's natural history illustrates or illuminates evolutionary biology in general.

Undoubtedly the most exciting of these has to do with the world-wide change of climate now in progress: but this I shall keep to the last.

The most obvious point is the paucity of bird species in general, and of passerines (song birds, etc.) in particular. Thus the number of regular breeding species in Iceland is only a little over a third of that

¹ Reprinted by permission from *Discovery*, vol. 21, No. 3, March 1950.

in Britain; but the number of breeding passerines is less than one-eighth of the British. In part this is due to the unfriendly climate and the barrenness of much of the island. Although Iceland barely touches the Arctic Circle, real trees cannot grow except in two small sheltered localities, and both vegetation and insect life have much less luxuriance and variety than with us in Britain, while the winter, of course, is such that very few species of bird could possibly live through it.

In Spitsbergen, farther poleward, we find a marked further drop, both in the total and the passerine percentage. The best way to bring this home is by means of a table:

TABLE 1.—*Breeding species of birds in Britain, Iceland, and Spitsbergen*

Country	Latitude	Regular breeding species	Passerines	
			Number	Percent of total
Britain-----	49°57'–58°40' (mainland) 49°51'–60°51' (with islands).	186	77	41.4
Iceland-----	63°20'–66°32'-----	69	9	13.0
Spitsbergen-----	76°26'–80°50'-----	25	1	4.0

There is, however, also the fact that Iceland is an island, and a fairly remote one, lying over 500 miles from the Hebrides (a little more from Cape Wrath, the nearest point of the British mainland), and close on 300 miles from Faeroe. Admittedly the distance north-westward to the Greenland coast is under 200 miles; but Greenland, especially in these latitudes, is so forbidding that very few species can have used it as a stepping-stone to Iceland.

Now remote islands invariably show a fauna and flora which is impoverished compared to that of the nearest mainland. This is usually set down to the difficulties presented to birds by a long sea passage, especially to small terrestrial species or those with feeble flight. In addition, an island is likely to have fewer kinds of habitats than a mainland area, and this may cut down the number of species which can find a permanent niche in its biological economy, even if they manage to reach it.

It is of course difficult to say just what birds are lacking merely because they have failed to overcome the sea barrier. Some apparent candidates turn out, on reflection, to be ruled out for other reasons. Thus the fact that among the thrushes the redwing breeds in Iceland and the fieldfare does not is not so surprising when we remember how the fieldfare seems much more definitely wedded to

tall trees to nest in, and (we may presume at least partly for that reason) does not exist so far north in Scandinavia as the redwing.

Then, with such a favorite as the meadow pipit to parasitize, it is at first sight puzzling that there are no cuckoos. It seems probable that the reason is the low density of pipit population. A cuckoo has to keep about a dozen fosterers' nests under observation if it is to succeed in its parasitism, and this would be impossible in Iceland.

The absence of the rock dove seems also surprising—until one remembers that the species seems to be dependent on weed seeds and other byproducts of human cultivation.

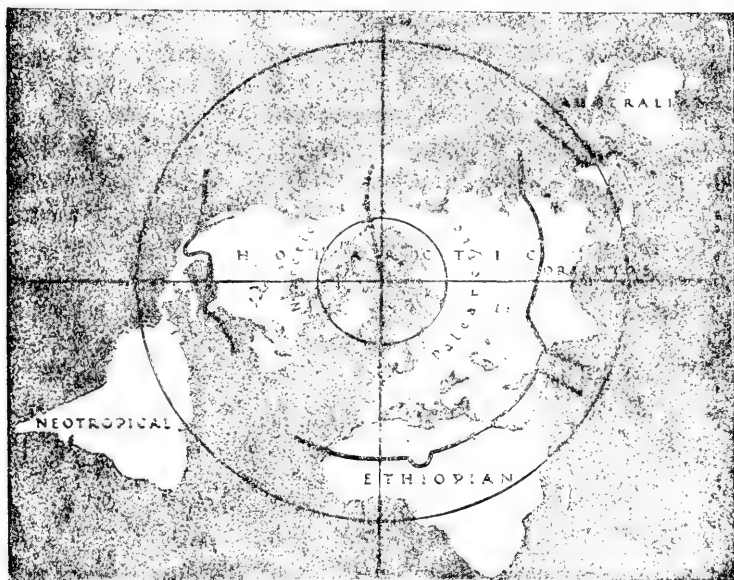


FIGURE 1.—Main zoogeographical regions characterizing the distribution of the land animals of the world. The Holarctic is normally divided into two sub-regions, the Palearctic (Old World) and the Nearctic (New World). In addition, there are separate ocean regions characterizing the distribution of marine forms, including sea birds; of these only the Atlantic region concerns us.

But I do find it puzzling that the ring ouzel, which likes rocky slopes and in Norway breeds as far north as the North Cape, has not established itself; and still more so that the dipper is absent, when its smaller relative, the wren, has been breeding in Iceland so long that it has evolved into a distinctive subspecies. Of course the streams by which the dipper lives would be frozen over in winter; but some of the dipper population of northern continental Europe migrates southward in winter, and the same might readily have occurred in Iceland, while the rest might have done what all the Iceland

wrens do, namely, take to the seashore. And I am pretty sure that if the house sparrow ever reached Reykjavik, the capital of Iceland, it would flourish and multiply.

The greatest puzzle, perhaps, is that posed by the Lapland bunting, which breeds in Greenland and north of the Arctic Circle in Norway, but not in Iceland, although it seems to traverse the island regularly on passage!

That for strong fliers the climate is the only obstacle is shown by the fact that since the beginning of this century the list of breeding species has been increased by nearly 10 percent, undoubtedly owing to the amelioration of the climate—a fact to which I shall return.

Again, swallows come to Iceland every summer (we saw some in the Westmann Islands) as do willow warblers, but neither species has yet been found breeding.

It seems that many species are all the time sending out scouts, so to speak, into areas where breeding is impossible but on the chance that one day they can establish themselves permanently. This seems a wasteful method, but natural selection always involves wastage. The most striking example is the painted lady butterfly (*Vanessa cardui*), which cannot reproduce itself regularly through the winter north of southern France, but in most years sends out vast numbers to Britain and other countries. The one we ourselves saw, by Lake Myvatn, was nearly 1,500 miles outside its permanent range!

Another interesting feature of broad geographical distribution is this—that Iceland is at the same time the westernmost outpost of a number of Old World bird species and the easternmost of some (but fewer) New World ones. Actually Lake Myvatn is the area of maximum overlap between the bird faunas of what zoologists call the Palearctic and the Nearctic regions, northern Eurasia and North America respectively.

Thus Iceland is the western limit of breeding range for such Old World species as whooper swan, greylag goose, snipe, golden plover, whimbrel, redwing, white wagtail (and indeed the entire wagtail genus); but it is the eastern limit for the otherwise New World species, great northern diver, Barrow's goldeneye, and harlequin duck. The ducks, by the way, well illustrate the complexities of geographical distribution—Iceland shows us not only several Old World species at their western limit, like wigeon, teal, common scoter, and tufted duck, but also a number of circumpolar or Holarctic species such as mallard, pintail, gadwall, and shoveler.

It is noticeable that all the New World species which breed in Iceland are hardy enough to inhabit parts of Greenland also. If the Labrador Current did not cool the east coast of Greenland and northern Canada so much below the temperature they ought to enjoy by virtue of their latitude, and the Gulf Stream did not warm Iceland and

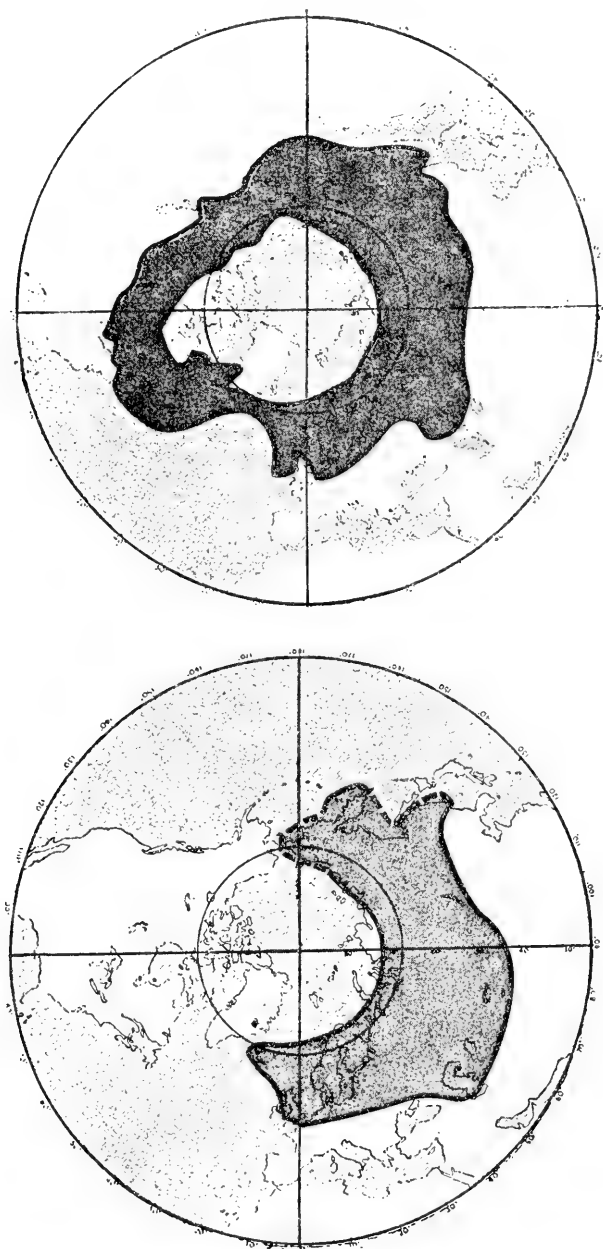


FIGURE 2.—Types of geographical distribution of Iceland birds. Upper, breeding and distribution of Holarctic species, the red-breasted merganser. Lower, breeding distribution of a Palearctic species, the wigeon, which extends from Bering Straits westward, to overlap with the great northern diver (fig. 3, upper) in Iceland. (Based on maps compiled by James Fisher.)

Spitsbergen and the northwest coasts of Europe so much above it, the contribution from the New World would presumably at least equal that of the Old.

There is, by the way, at least one plant in Iceland which is of New World origin. The sea-rockets, *Cakile*, are shore-dwelling crucifers with lilac flowers. Two Icelandic botanists, Dr. and Mrs. Löve, have recently shown that the sea-rocket of Iceland does not, as had been generally assumed, belong to the species found in Scandinavia and with us in Britain, *Cakile maritima*, but reveals itself, both by its slightly different form and its doubled chromosome number—36 instead of 18—as the North American species, *C. edentula*. This holds also for the sea-rockets of the Azores: the Löves' conclusion is that the Gulf Stream has been responsible for the appearance of the American sea-rocket in these otherwise Old World islands, by transporting the seeds in its slow, warm drift.

At various times in the geological past, there was a land connection between the Old and the New Worlds across what is now the Bering Straits, and probably also, though not so often or so long, across the North Atlantic, along the line still indicated by the submarine ridges between Greenland, Iceland, Faeroe, and Shetland. The climate in the regions connected by these land bridges was then less rigorous, and there was more uniformity of animals and plants in the Holarctic region than now. But isolation and time saw to it that the inevitable differences were accentuated, and meanwhile the New World fauna received large additions from the Central and South American region, which were very different from the immigrants that the northern Old World received from Africa and southwestern Asia. Thus eventually two quite distinct faunas and floras, the Palearctic and the Nearctic, were differentiated—distinct, but with a number of elements obviously of common origin, and still with a considerable number of species shared by both and therefore classed as if Holarctic.

The greater isolation of the two regions today may possibly be due not only to the breaking of the land bridges between North America and the Old World, but to an actual increase of the distance across the Atlantic, caused by the slow drifting away of America from Europe.

This was postulated by Wegener in his theory of Continental Drift. Iceland is well situated to test the theory. The position of certain points should be determined with great accuracy, so that after a lapse of years even a few yards' shift could be detected. German scientists had begun on this project before World War II, and had set up a number of triangulation points in Iceland. However, the Icelanders were so suspicious that these might be camouflage for some military project, that they destroyed them all—another of the innumerable minor tragedies of modern war!

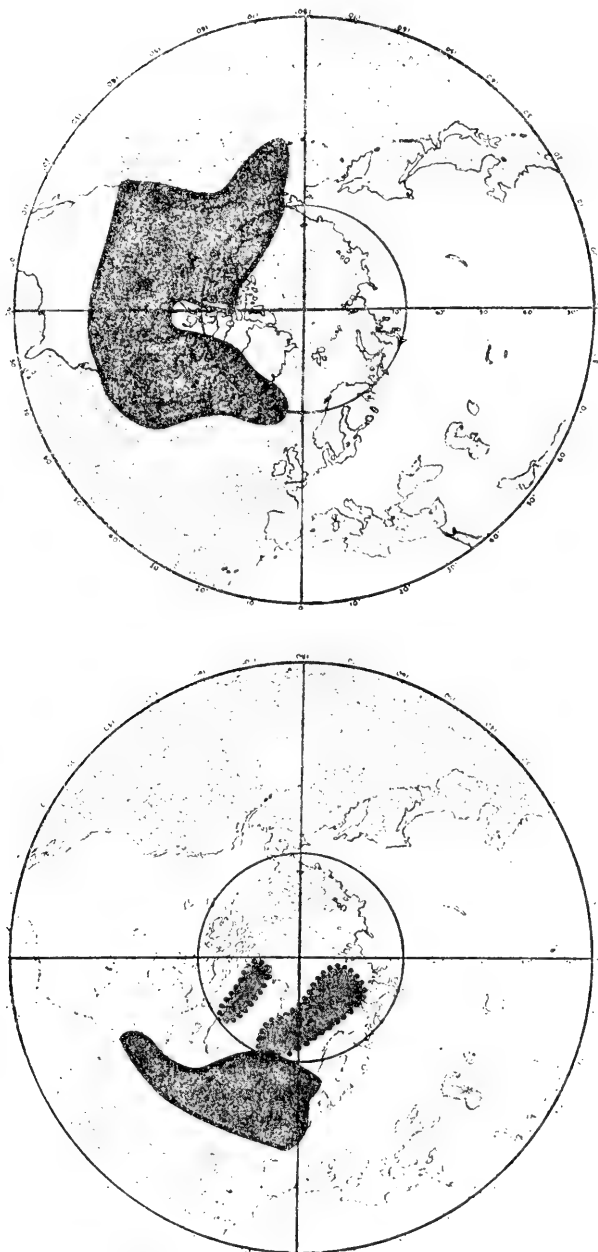


FIGURE 3.—Types of geographical distribution of Iceland birds. Upper, breeding distribution of a Nearctic species which extends to Iceland, the great northern diver or loon. Lower, breeding distribution of two Atlantic species, the Arctic little auk and the North Temperate gannet. The two just overlap in northeast Iceland. (Based on maps compiled by James Fisher.)

But there are other faunas represented in Iceland. An important one is the North Atlantic fauna, mainly of course of marine creatures, but emerging into the air in the form of a number of sea birds which exist on both east and west coasts of the North Atlantic, and on suitable islands in between. Gannets, guillemots, razorbills, and puffins are examples. This North Atlantic bird fauna seems to have differentiated comparatively recently—perhaps as a result of the drifting apart of northern America and northern Europe—and consists of immigrant types from other regions—from the Arctic, from the Pacific round Cape Horn, and from the Indian Ocean.

Finally—believe it or not!—the Antarctic fauna is represented in Iceland. The bonxie or great skua is merely a subspecies of a dominant species widespread in the Antarctic and sub-Antarctic regions. Many high-latitude birds migrate to the other hemisphere after breeding, thus perpetually avoiding winter. Our bonxies must be descended from some Southern Hemisphere migrants which stayed to breed in their off-season area—one cannot say “in their winter quarters.”

Thus we have in this one island representatives of five faunas—North Hemisphere Old World, North Hemisphere New World, North Atlantic, circumpolar South Hemisphere, and circumpolar North Hemisphere.

This last includes two subdivisions—the true Arctic fauna, with such Iceland birds as little auk and glaucous gull, and the sub-Arctic and north-temperate forms shared by New and Old Worlds, such as wheatear, raven, mallard, and Slavonian grebe.

One of the interesting things that came to our attention was the frequent distinctiveness of the local Iceland race or subspecies of various species of birds. For instance the Iceland wren is both larger and darker than ours in Britain, and the Iceland redpoll is also larger than our British subspecies, the so-called lesser redpoll, as well as having a recognizably different call note. The redpoll, by the way, is an example of an Iceland bird which is small in size but yet is found in Greenland and North America, as well as in the Old World, so that it, like the wheatear, is Holarctic. But, unlike the widely spreading ducks, both these small birds break up into numerous well-marked subspecies.

The wren is curious in this respect. Although it has produced separate and distinctive subspecies in Iceland, Faeroe, St. Kilda, and Shetland, it is uniform over the whole of western and central continental Europe. The separation of Britain from the Continent has not resulted in the evolution of a British subspecies, though this has happened with many other birds, of which our pied wagtail, so easily distinguishable from the continental white wagtail, is an example. Why this is so, is a real puzzle.

I mentioned that the Iceland redpoll and wren were larger in size than ours. This is an example of an interesting general rule—that, in general, warm-blooded animals are found to be slightly larger the nearer they live to the pole; further, in mammals, the relative size of ears, tail, and limbs tend to diminish—a phenomenon strikingly illustrated by the tiny ears of the Arctic fox as compared with the huge flaps of the fennec fox from the scorching deserts. These changes are undoubtedly adaptations, working to reduce heat loss in cold climates and to promote it in over-hot ones.

Thus some of the special characters of Iceland birds are adaptations to climate while others, like the color of the Iceland wren, seem to be more or less accidental results of isolation. But there is a third class of difference, and perhaps the most interesting—the differences in behavior and song. Some of these differences, like the harsher song of the Iceland wren, are again aspects of the distinctiveness of the local subspecies. Others seem to be due to the birds being on the margin of their range, in surroundings quite different from the normal. Thus, as already mentioned, the Iceland wren out of the breeding season has to become almost exclusively a shore bird.

Frequently, however, the reason is more subtle—the absence of competition from close relatives which have not reached this part of the species' range. Thus, in Britain, snipe are inhabitants of open country, so that it was surprising to find them quite common in the one of Iceland's two woods that we visited. James Fisher hit on what I am sure is the solution—namely that there are no woodcock in Iceland. With us, woodcock occupy the habitat provided by boggy woods. But where they are absent, the snipe avail themselves of this as well as of their normal open habitat.

But the absence of close relatives may have another effect. When two closely allied species come into contact in the same area, it is in general a biological advantage for them to proclaim their distinctiveness by some characteristic difference of plumage or voice. This will help to prevent actual or attempted cross-breeding, trespassing, and other wastes of time and energy. In Britain, the closely related meadow and tree pipits are not only restricted to different habitats, but sing quite distinctive songs. With us, the meadow pipit is exclusively a bird of moors and heaths and other open country, and its song is a rather feeble descending scale gradually accelerated into a little trill, given as the bird parachutes down after having flown up from the ground. The tree pipit, on the other hand, demands scattered trees, and has a much more striking song; this is also given in the air while floating down, but the flight starts from (and often ends on) a tree perch.

Here the need for distinctiveness cannot well be met by coloration, since both species are adapted to concealment by cryptic coloration;

but the songs, given high in the air, are obvious trade-marks for the two species.

In the Iceland birchwood where we found snipe, there were also meadow pipits. We would never have dreamt of finding meadow pipits in such a place in England, and their presence was clearly due to the absence of their close relative and competitor, the tree pipit. What is more, the song of one of them had a distinct tree pipit flavor, and it was begun from a tree perch.

Finnur Gudmunsson told us that in western Iceland he had once spent a couple of hours stalking the singer of a song which was wholly unknown to him: he eventually shot it for identification purposes—only to discover that it was an ordinary meadow pipit! This, too, was in a birch area, though the birches here were only scrub. Thus the relaxation of the need for distinctiveness seems to have permitted the song to change.

The meadow pipits of open country in Iceland have so far not been heard to give any intermediate or markedly abnormal song (though one we heard in the Westmann Islands was exceptional for its brilliance). Possibly the woodland and scrubland birds are evolving into a distinct ecological race.

There remains to mention one amusing incident. In this same wood, we found a redwing's nest quite high in a birch tree. Now in Iceland the redwing, that attractive little thrush, is normally a confirmed ground nester, though in Norway it frequently builds in trees, and Dr. Gudmunsson was quite impressed by this unusual event. Then on Myvatn we saw another tree nest, some 8 feet up in a willow; and Dr. Gudmunsson grew really excited—until Sigfinnson, the farmer-naturalist, reminded him that this had been the latest season in living memory, and that the ground had been deep in snow when the breeding urge took the redwings. Seeing that they thus so readily revert to ancestral habit under the stress of necessity, it is rather curious that they do not normally do so as a matter of convenience wherever trees or bushes abound.

Finally, I come to what to me is the most interesting point of all—the bearing of field natural history in Iceland upon the fascinating and basic question of a world-wide change in climate.

Professor Ahlmann, the well-known Swedish geographer, in a recent issue of the *Geographical Journal*, has summarized all the evidence on this subject. He concludes that in the Northern Hemisphere a widespread amelioration of climate is in progress, most marked in higher latitudes. It began about a hundred years ago, but has been especially marked in the last two decades. The most likely explanation (which would be assured if we get evidence of a similar amelioration in the Antarctic, as it is hoped to do from the joint Norwegian-British-Swedish expedition now operating there) is that

it is world-wide, and due to increased heat from the sun, which in its turn operates by altering the world's great system of atmospheric circulation.

The evidence is of every sort—increased temperatures, spectacular regression of glaciers, changes in the position of main low-pressure and high-pressure areas, alterations in rainfall and snowfall, desiccation in lower latitudes (including the drying up of East African lakes), enormous shrinkage of the polar pack ice, enlarged growth rings of trees, and finally changes in the distribution of many animals and plants.

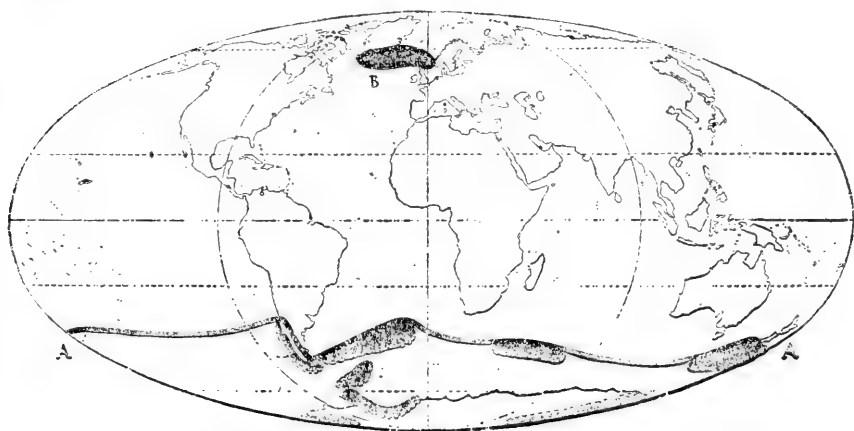


FIGURE 4.—Breeding distribution of the great skua, a circumpolar species from the Southern Hemisphere, which has given rise to one Northern Hemisphere sub-species. The shaded parts represent the actual breeding areas of the various Southern Hemisphere subspecies. (Based on map compiled by James Fisher.)

On this last point Iceland provides a great deal of evidence, since it lies on the sensitive limit between sub-Arctic and Arctic conditions. We know from historical records that for over 400 years the early colonists successfully grew barley, but that soon after 1300 this became impossible. But now, to quote Ahlmann, “the present shrinkage of the glaciers is exposing districts which were cultivated by the early medieval farmers but were subsequently overridden by ice.”

The ensuing cold spell of about 600 years has been called the Little Ice Age; it seems to have been the coldest period since the retreat of the ice after the last major glacial period. At any rate, about 1880 the Iceland glaciers reached their maximum extension for some 10,000 years, while the warmest period since the end of the Ice Age seems to have been the few centuries just before our present era.

As showing how sensitive animals may be as climatic indicators, Finnur Gudmunsson told me that in the warm spell just before the Christian Era, the dog-whelk (*Purpura*) was found all along the north and east coasts of Iceland, while today it stops dead at the

northwest and southeast corners. (The slightly hardier whelk, *Buccinum*, still occurs all round the island.)

To come down to the present, the last few decades have seen drastic changes in the fish which are Iceland's prime economic support. Herring, haddock, halibut, and especially cod have extended their range northward in Greenland (the cod at the rate of about 24 miles a year for close on 30 years); and cod and herring are moving north from Iceland, so that anxiety is beginning to be felt about the future of the fisheries.

Meanwhile, there have been extraordinary changes in the bird population of the island. No less than six species—nearly 10 percent of the previous list of breeders—have only started to breed in Iceland during the present century. There is the tufted duck, which arrived in 1908, and has spread so fast that now it is the second commonest species on Myvatn; three gulls—the blackheaded, herring, and lesser blackback; the coot and the starling, both only after 1940, the latter still confined to cliffs near its presumed landfall in the southeast.

Further, the oystercatcher, previously confined to the southwest, has shown a spectacular spread northward. The blacktailed godwit and the gannet have also pushed up the northern limit of their range, the latter having established three new colonies on the north and east coasts.

Meanwhile, the little auk, the only true high Arctic species in Iceland, has entirely deserted one of its two breeding colonies in the northeast, and the other has dwindled to almost nothing; apparently Iceland is no longer cold enough for it. Finally, some plants are moving north—notably the bilberry (*Vaccinium myrtillus*) which has colonized areas previously reserved to dwarf willows; and there have been similar shifts in some of Iceland's insects.

All these changes have become much more pronounced within the last 10 to 15 years.

We in Britain have had numerous examples of bird species spreading northward in the present century, including some birds which have been doing the same thing in Iceland, like the tufted duck, and others like the black redstart which are quite recent invaders of these islands.

All such observations take on new interest when it is realized that they can contribute to our understanding of a world-wide and secular change of immense significance for our human future; and one which is unique, since, in Ahlmann's words, "It is the first fluctuation in the endless series of past and future climatic variations in the history of the earth which we can measure, investigate, and possibly explain."

I have certainly returned from my Iceland trip with a new awareness of the importance (in addition to the interest) of field natural history.

PRAYING MANTIDS OF THE UNITED STATES, NATIVE AND INTRODUCED¹

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[With 9 plates]

A person encountering a praying mantid for the first time usually does so in one of two ways. He may unexpectedly discover a large striking insect, late in summer or in fall, climbing over garden shrubbery or perching near a blossom waiting for a meal to appear in the form of some unlucky insect. Or perhaps he will see a mantid on the side of a house, or find one near a window that was brightly lighted the previous evening. The second type of encounter usually follows the discovery of a light-brownish fibrous object attached to vegetation, a fence post, or other support, during fall or winter. Thinking it to be the cocoon of a moth, the budding naturalist may take it indoors to witness the emergence. A few weeks later he will be astounded to find that a hundred or more small crawling insects, each with perfectly developed "praying" front legs, but without wings, have emerged. If the mantid egg cases are not confined in a jar or other container, the young mantids may not be noticed until a disconcerted housewife finds them crawling up curtains and on the ceiling.

At any one locality in the United States only a very few kinds or species of mantids occur, and often there is only one, while some of the more northern parts have none at all. Altogether, 19 kinds of mantids are known to occur in the United States, most of them inhabiting the Southern States. Careful collecting and close study of museum specimens may eventually show that we have somewhat more than 19 kinds. In tropical countries new species are continually being found and given scientific names for the first time. Throughout the world, there are more than 1,500 species, most of which are tropical or subtropical in distribution, and so within the United States we have merely a northern fringe of a great subtropical group.

¹ Photographs by Edwin Way Teale are from *Grassroot Jungles* (Dodd, Mead & Co., 1937) and are here published by the kind permission of Mr. Teale. Photographs by John G. Pitkin are published with his permission. The specimen of *Mantoida* illustrated was lent by the Museum of Zoology, University of Michigan, through the courtesy of Dr. T. H. Hubbell. This and other preserved specimens were photographed at the Smithsonian Institution by Floyd B. Kestner.

Mantids often stand motionless for long periods, holding their front legs in a folded position ready to catch prey, and peering intently at nearby objects. This habit of holding up the folded front legs has given rise to the term "praying" in the common name, and the distinctive attitude of these insects when in such a waiting position has stimulated the imagination and semireligious beliefs of country people of many lands for several centuries. "Preying" would be more realistic, because the only thing mantids would seem to pray for is a square meal. The name *mantis* is derived from a Greek word originally meaning a prophet or seer. Either *mantis* or *mantid* is an acceptable common name, with *mantids* being preferred to *mantises* or *manties* in the plural. In some parts of the United States mantids are called "rear-horses," "devil-horses," and "mule-killers," and in the Southwest they are often called "campomoche."

It is most interesting that two Oriental and one European species of mantids have been unintentionally introduced and are now widespread in the Northeastern States. As a farm boy in western Massachusetts none of these remarkable insects came to my attention, for no native mantids live there, and the European mantid was then known in this country only in western New York State. Later, near Washington, D. C., I first made the acquaintance of the introduced Chinese mantis and its "cousin" the narrow-winged mantis, as well as the most northeastern of our native species, the Carolina mantis. In 1949 the European mantis was found to have spread to Vermont and Massachusetts, and during 1950, in the same fields I tramped as a youth, dozens of specimens were to be seen in a single day. Hundreds of Americans who had never encountered our native mantids have met with these visitors from abroad, have first been amazed at their strange appearance, then have been intrigued by their unusual habits. During fall, most museums and science institutes near areas where mantids occur receive a continual stream of inquiries about mantids from people who have been surprised to find one of these insects or who wish to instruct their children about their habits, worth, or cage-rearing possibilities.

RELATIVES OF MANTIDS

In the technical classification of insects the many species of mantids constitute a family called the Mantidae.² Mantids belong to the broad group or order of insects called Orthoptera, which includes also cockroaches, katydids, grasshoppers, crickets, and walkingsticks. Cockroaches show closest relationship to mantids, the head shape and the structure of parts of the thorax and abdomen indicating definite affinities. The front legs, highly specialized in mantids for seizing prey,

² Sometimes given as Manteidae.

are so conspicuous, and the bodies of most species are so long and relatively slender, that superficially there is little resemblance between mantids and the broad and flattened roaches. It might be supposed that, like roaches, mantids would have a long and ancient lineage preserved in fossil beds dating far back in geological time. Such, however, is not the case. Although ancestors of modern roaches occur widely as far back as the Carboniferous, when coal was being formed, fossil mantids have seldom been found, and then only in the Miocene and Oligocene (according to Chopard, 1949), when the evolution of the horse was moderately advanced and the age of dinosaurs had long since passed.

APPEARANCE AND ANATOMY

Compared to most insects, mantids are relatively large, the more conspicuous northeastern species usually being 2 to 4 inches long when mature. The mantids living in the South and Southwest seldom exceed $3\frac{1}{2}$ inches in length, and there are several an inch long, or even less. Mantids are elongate, relatively slender, and usually some shade of green or brown. One individual may be green and another of the same species brownish buff, while a third is partly green and partly brown, this much variation occurring in the color of many species. The most noticeable features are the front legs. Although the middle and hind legs are slender and simply used for walking, running, and, rarely, jumping, the front legs bear sharp spines and fold in a remarkable hinged manner that enables the mantid to reach forward, seize a fly or some other insect, and bring it to the mouth. In addition to seizing prey, the front legs are used to some extent for walking.

Predatory front legs of this general type are not limited to mantids. Front legs specialized for grasping prey have evolved in the Mantispidae, a curious family of neuropteroid insects whose larvae usually develop in the egg sacs of spiders, and certain raptorial families of true bugs, such as the ambush bugs (Phymatidae), show a comparable development of the front legs. In each group the specialized forelegs differ in certain fundamental details, and it is evident that their evolution has been along independent though parallel lines.

The head of a mantid is triangular in shape when seen from the front; the compound eyes are at the upper outer corners, and the mouth opening is at the lower corner. Each compound eye is composed of several hundred tiny facets, each facet receiving the light from a fraction of the entire field of vision at one time. In addition to the compound eyes, which are the most important organs of sight, there usually are three ocelli. The latter are simple eyes, each of one facet, which are arranged in a triad on the top of the head. They supplement the compound eyes, enabling the insects to respond to changes in light intensity better than when the compound eyes alone

are used. The antennae, or "feelers," are long slender sensory organs which presumably function as organs of smell and hearing. No conspicuous tympanum or "ear," such as occurs on the side of the first abdominal segment of grasshoppers, or near the front "knees" of most katydids and crickets, is found on the body of a mantid. Near the base of each antenna, however, in the second segment, is located a group of sensory cells comprising Johnston's organ, and this organ is sensitive to vibrations and other stimuli related to sound waves.

The head is attached to the section of the body immediately behind it (pronotum) in a way that enables it to be turned very readily to face different directions; scarcely any other insects are able to turn the head as freely. Experimental biologists have found that some mantids have a remarkable tenacity of life with the head removed. Such specimens are known to have lived several days, to have mated, and to have deposited normal egg masses.

FOOD

Mantids feed entirely on other animals, in nature consisting almost entirely of insects and closely related creatures caught alive. Instances of small birds, lizards, or mice being eaten by mantids have been reported, but they are rare and in some cases the result of incorrect observations. A mantid that has been surprised or that comes face to face with an enemy often rears backward, partially spreads the wings in an attempt to frighten the assailant, and adopts a sparring attitude with the forelegs held up in front of the face. More than once a mantid sparring with a sparrow or other small animal has attracted a crowd of people hurrying along a city street.

Young mantids necessarily capture small insects, such as fruit flies. In the more advanced nymphal stages and when mature, large flies, grasshoppers, caterpillars, butterflies, moths, cockroaches, and other large insects are caught and eaten. The less appetizing portions, such as the wings and legs of grasshoppers, are usually discarded. In the course of feeding, quite edible portions of the prey often become detached and fall. Since the mantid is usually on vegetation or other object some distance from the ground, the fallen portions are not retrieved; in fact it is not natural for mantids to pick up fragments of dead food. As an example of the appetite, an adult female of the Carolina mantis has been known to eat 10 adults of the German cockroach, plus a roach egg case, in a period of 2½ hours, though this is probably far above average food requirements.

A Chinese mantis that I kept indoors ate stink bugs with no apparent concern for the strong-smelling scent gland, and one of my friends told me of another specimen in captivity eating wasps and honey bees. One day it seized a hornet and was apparently stung near the mouth

when it began to feed on the latter's abdomen. The mantid, obviously hurt, held the hornet, still in a firm grasp, at some distance from the head for a few minutes. Then, with the immediate effects of the sting worn off, it ate the hornet.

Under favorable circumstances, such as in a field of goldenrod near an apiary, mantids may feed on honey bees a great deal, and a study made near Philadelphia (Thierolf, 1928) showed that honey bees, when available, are one of the favorite insects eaten by the Chinese mantis. In Hawaii a survey was made (Hadden, 1927) of the food of the narrow-winged mantis. The resulting list of the different insects eaten includes 2 species of grasshoppers, 1 katydid, 1 aphid, 2 butterflies, 1 moth, 15 flies, and 6 wasps and bees, in addition to members of its own species. Hadden found that the mantids were careful when catching wasps that are equipped with a painful sting and would drop them when stung, then lick the wound caused by the sting.

Adults of the Carolina mantis were offered scorpions by a Texan entomologist (Breland, 1941a). One mantid seized a scorpion so that the tail was pinioned, and consumed it. However, another mantid made the mistake of grasping a scorpion in such a way that the tail was free, and the scorpion immediately swung the tail over and stung the mantid on the head. The scorpion was released immediately, and the mantid carefully avoided it from that time on. Blood oozed from the wound for about 3 hours, and 2 days later the mantid appeared, superficially, to be normal. That the venom had taken permanent effect was suggested by the great difficulty the mantid had in eating. Although prey was caught, chewing and swallowing seemed nearly impossible. About a week after being stung, an abnormal egg case was deposited, and 10 days following the injury the mantid died.

As a general rule ants are not attractive as food to most species of mantids, although some North African desert mantids are reported to be fond of them.

Mantids usually wait motionless until their prey comes within reach, or stand and sway from side to side, but sometimes, apparently when very hungry, they may stalk a nearby insect that represents a potential meal. Sometimes the prey is touched lightly with the antennae before the front legs flash forward and make the seizure. It is usually the insect that moves occasionally that gets captured; motionless insects often pass unnoticed. The extremely stealthy habits of most mantids are in contrast to the great speed with which some desert mantids are able to run. These are usually ground-dwelling creatures, and under arid conditions in an environment often composed of

a strictly limited number of plants and animals the struggle to survive is intensified and a premium is placed on actively aggressive habits.

Although mantids are thought to detect their prey mainly by sight, the Carolina mantis can capture insects in the dark, and most of the eastern species often mate and lay eggs in the dark. Some insects are thought to have periods of rest comparable to the sleep of higher animals. For example, certain wasps go to sleep with their mandibles tightly clasped on weed stems, the body being held out vertical to the stem. Some butterflies sleep on flowers and are plainly drowsy when picked up at night. I have kept numbers of Chinese and narrow-winged mantids in cages and have made a point of quietly going to their cages after they have been in the dark for several hours and inspecting them with a weak flashlight. Always they have been alert, with a look of searching interest and with occasionally moving antennae.

Except for a few desert species, which dwell mainly on the ground, mantids spend the bulk of their time climbing over weeds, grass, and shrubbery, or just waiting. The kinds of insects available as food will thus vary under different conditions. Mantids occasionally visit lights at night or frequent sweet materials to which other insects have been attracted, and there they find good hunting.

My observations on the Chinese and narrow-winged mantids show that the majority of insects captured are consumed first at the head or near the head, though occasionally the abdomen is eaten first. When another mantid is caught, the head is often eaten first, but I have seen the thorax eaten through near the base of the wings, with the head, prothorax, and front legs dropping unnoticed while the successful aggressor continued feeding steadily on the remainder of the thorax and the abdomen.

Some tropical mantids are specialized so as to resemble flowers, or so that their colors blend with those of plant foliage. This is thought to aid them in capturing prey, the hapless victims not sensing the danger until it is too late. In southeast Asia a species (*Hymenopus coronatus* (Olivier)) that varies in color from white to pale pink in the late nymphal stages has the habit of crouching amid certain blossoms, the petals of which its legs and other body parts closely resemble. Two other species, *Gongylus gongylodes* (Linnaeus) of southeastern Asia and *Idolum diabolicum* Saussure of east Africa, have brilliant blue colors on certain expanded parts of the body. The mantids display themselves on plants so that these colors are exposed to the sun, and the widely adopted belief is that bees, flies, and other flower-loving insects are thus lured to their doom.

Hardly less remarkable is the superficial resemblance of a few tropical mantids to other insects of the same environment that evidently are distasteful to birds, monkeys, and other predators. The

first-stage nymph of *Hymenopus coronatus* resembles a bug of the family Reduviidae, which probably can inflict a severe bite in addition to tasting bad. In India certain mantids resemble ants, while in Indo-China a common type of arboreal tiger beetle (Cicindelidae) is the model for a mantid (*Tricondylomimus coomani* Chopard). The subject of protective mimicry is a highly controversial one, and for the present purpose it is sufficient to invite attention to these striking resemblances on the part of a few tropical species and to suggest the stimulating interest that might come from investigations by people situated where such species occur.

GROWTH AND MOLTING

The eggs of mantids hatch in spring and early in summer, unless they are induced to hatch sooner by a warm climate or by being brought indoors. In the northeastern United States mantids usually hatch late in May and in June, and they customarily mature in 2 to 3 months, the adults occurring from late in August or in September until frost kills them or they die of other natural causes. In captivity some mantids have lived as long as 4 to 5 months after reaching maturity, but the average is much less.

Newly hatched young, called nymphs, resemble the adults except that they are small and delicate and have no wings. Like other Orthoptera and the more primitive insects in general, mantids have no grub or caterpillar stage. These stages, technically referred to as larvae, occur only among higher insects, beginning with Neuroptera (hellgrammites, ant lions, aphid lions) and including Diptera (maggots of various kinds), Lepidoptera (caterpillars), Coleoptera (beetle grubs), and Hymenoptera (larvae of bees, wasps, and ants).

The egg cases, technically known as oöthecae, of most mantids have a hatching area on the surface of the case that is opposite the side that is attached to a support. Chambers or passageways lead from this hatching area directly to the eggs. The emerging nymphs wriggle, head foremost, up these passageways to the surface and there hang head down while they prepare to get the use of their legs. At 7:15 one morning early in June I noticed that about 20 nymphs were beginning to emerge from one of my egg cases of the Chinese mantis. They were a rich yellow color, with dark eye spots and with the legs and antennae limp and folded back beside the body. Within half an hour 100 or more nymphs were out, and the whole wriggling mass was hanging from the egg case. Some had their legs free and were already crawling, though still yellow in color. By 9 o'clock all were free, nearly all had turned to a neutral gray color, and they were ready to be released on shrubs in my garden. A cluster of membranous shreds, of indefinite shape, remained hanging from the hatching area of the egg case.

When the embryo has developed into a well-formed nymph within the eggshell, it is ready to push through the head end of the shell and wriggle toward the open air. Egg masses of Chinese and narrow-winged mantids that I have collected for hatching have shown that the great majority of nymphs from any one egg case appear the same day, usually within an hour. A few early nymphs, perhaps as many as 10, may appear a day or a few days previously, and a week later occasional stragglers may still hatch, but hatching is very much a dramatically sudden event. Some exceptions, mainly among tropical species, have been reported.

When the newly hatched nymph, with limp legs and antennae, wriggles into the open air and, from its own weight, hangs downward, it sheds its transparent skin almost at once. Following this act, the legs stretch out, the body takes on an erect shape, and the little nymph is soon ready to walk. This is the true first-stage nymph, and the molt that has just occurred is the intermediate molt, so named by Uvarov who carefully described a corresponding and fully comparable event during the hatching of grasshoppers. The cast skins of the intermediate molt, almost embryonic skins as it were, constitute the membranous shreds hanging down from the hatching surface after hatching has occurred. The newly emerged nymph often remains attached to the shed skin for a short time while the body and legs are hardening, and the nymph may appear to be dangling from silken threads. Within a few days after hatching the effects of weathering have removed these cast skins from the old egg case.

Following the intermediate molt, the skin is shed six to nine times before maturity is reached. The number of molts differs somewhat in different species and is variable within the same species. At each molt the size increases, and after the later molts the buds or pads of developing wings become more noticeable. Most of our mantids have long, fully developed wings when mature, but some are entirely wingless, or have very short wings, or the wings of one sex only are short or entirely lacking. Females are usually larger and more robust than males.

Although first-stage nymphs are all similarly colored, later stages may show that either green or brown is dominant. Attempts have been made to show that these colors are correlated with similar environmental backgrounds, or with weather conditions, but reliable information on these matters is still insufficient.

MATING AND THE EATING OF MALES

There is a widespread belief that, following mating, the male mantid is always eaten by the female. This actually happens in many instances, but with some of our more common species the males usually escape. In some species males may notice the females and

be so strongly attracted, prior to the sexual union, that nearby disturbances are largely disregarded.

One October afternoon I went searching for insects to feed a captive Chinese mantid female. Grasshoppers were scarce and only a few small insects were found, in addition to a male of the narrow-winged mantis and one of the Chinese species, which I placed in the cage. When I reached home 20 minutes later, the female had seized the narrow-winged male and was eating his head. He was consumed in about half an hour, the legs, wings, and end of the abdomen being discarded. She then cleaned her front legs with her mouth and began leisurely to move about the cage. I saw her move toward the male of her own species and began to think he was destined to be eaten at once, but she turned away from him when she was about 2 inches distant and slightly below him on an adjacent vertical wall of the cage. He had been eyeing the female intently, and just as she turned away he leaped with partly open wings upon her. Soon he had hooked his front feet securely beneath the bases of her closed wings, and the ends of the two abdomens had effected a union. After the first flurry of activity both mantids were quiet, though the female, carrying the male, moved about the cage. They separated 3½ hours later, which was after dark, without the male being attacked. Soon after dawn the next morning, however, the female had seized her mate around the thorax with the left front leg, and while his head was held to one side with the right leg she began her meal by eating through the base of the pronotum.

In the unnatural confinement of a small cage the eating of males following mating may be more frequent than under normal field conditions. Mantids often mate several times, though one mating appears sufficient to insure fertile eggs. Females that are kept isolated will often deposit egg masses that appear perfectly normal, though there has been no mating, but invariably (with the exception of a few species that have no males) they do not hatch. A small percentage of the egg masses of the Chinese and narrow-winged mantids that I have collected and confined for rearing have not hatched. Whether some of this failure to hatch is due to lack of fertilization is not known.

Unlike many crickets, katydids, and grasshoppers, "voices" play no part in the "courtship" of mantids. The several forms of stridulation exhibited by those Orthoptera, ranging from the delicately exquisite tinkling of our small bush crickets (*Anaxipha* and *Cyrtoxipha*) to the raucous rasping of the true katydids (*Pterophylla*), which may be heard for half a mile on a favorable evening late in summer, are among the best known of all the sounds of insects. Like nearly all the roaches, mantids have on their wings, legs, or other organs no stridulatory equipment for expressing their disposition in "song."

Judd (1950) states that the European mantis is capable of stridulating. He refers to the defensive attitude of caged individuals that faced intruders with wings outspread and held vertically above the body, at the same time curling the abdomen upward and swinging it backward and forward, its sides making a rasping sound by rubbing on the veins of the hind wings.

EGG-LAYING HABITS

The eggs of mantids are laid in groups of a dozen to 400, or thereabouts. Each oötheca of the Chinese and narrow-winged mantids contains an average of 200 to 300 eggs, according to the studies of Fox (1939b, 1943). The eggs are deposited in layers in the midst of a thick, frothy liquid, which soon hardens and becomes fibrous. Each layer of eggs may consist of two or more rows, one above the other, all leading up to the hatching area and the outside by the same passageway. The protective covering is usually straw-colored or some shade of gray or brown. For the most part, each species of mantis deposits egg masses of a distinctive shape, some being elongate, some globose, others ridged or bearing a peculiar apical spine. Very unusual tropical oöthecae, some not yet associated with any named species, have been described. There is one type, for instance, that consists of a chain of eggs laid on a leaf; another is a little cluster of eggs suspended within the empty hollow of a thin parchmentlike bladder attached like a nut to vegetation. (See Chopard, 1938.)

A female usually deposits 2 to 5 egg masses, as many as 20 in some tropical species, during a period of weeks, and the size varies. Egg masses are usually attached to vegetation, such as grass or weed stems, twigs of shrubs or trees, less often to stones, fence posts, or the walls of buildings. In my experience the majority are within 3 feet of the ground, but I have found them in pine trees 8 feet from the ground.

The Carolina, Chinese, and narrow-winged mantids apparently always oviposit while standing with the head directed downward. When the oviposition site has been selected, the mantid stands firmly in position, and a whitish material much like toothpaste begins to appear at the end of the abdomen. The three down-curved, paired, fingerlike valves of the ovipositor manipulate the material rapidly, apparently beating it up and introducing air bubbles, while the end of the abdomen steadily moves from side to side and up and down. Eggs, which originate in the paired ovaries within the abdomen, are deposited in this soft matrix, though they are not readily seen during the process. The whitish matrix is the product of accessory glands. Exactly how the parallel chambers through which the hatching nymphs emerge are made so regularly is still difficult to understand.

An equal amount of the matrix is placed each side of the central section where the eggs are located. The top of each layer is finished in such a way that the final product is characteristic of the species, and the lower end is smoothed off when egg deposition is completed. Within an hour the matrix is reasonably dry and has a spongy texture. Though nearly white at first, darkening soon begins, and within a week or so the gray or brown color typical for the particular species is the rule.

Egg-laying by our best-known species most often occurs late in the day and frequently after dark. Females do not look around during the oviposition process but are guided by instinct and the sensory organs located at the end of the abdomen. To me the ability of each species consistently to produce its own characteristic type of oötheca, although superficially equipped with the same type of ovipositing organs, is one of the most remarkable characteristics of mantids. Doubtless for thousands of years each species has passed this ability, mainly expressed in blind but unerring instinct, down to succeeding generations. Such is the nature of species, each differing from others in definite, though not always grossly conspicuous, ways.

FLIGHT AND OTHER METHODS OF DISPERSAL

Most fully winged mantids occasionally fly, the flights varying in extent from a few yards to several hundred yards or more. Females approaching the time of egg-laying are usually quite heavy-bodied, since the abdomen is filled with eggs, and in that condition they are not so inclined to fly as during the first 2 weeks or so after maturity is reached, nor so apt to fly as the males. Mantids are sometimes attracted to lights at night, with the result that they are found near windows the following day. Specimens have been found at the top of the Empire State Building in New York City.

The natural spread of a species of mantid into territory not previously occupied is by flight, in the case of winged species, and by crawling. Many years may thus elapse before a species travels more than a relatively few miles. Occasionally winds may add greatly to the distance covered by a mantid in flight. Artificial transportation by human agencies has in modern times become rather important in the dispersal of mantid species to areas where they did not originally live. Such introductions are largely by means of the egg masses, which are often unintentionally carried attached to shrubs, hay, lumber, or other materials. Notable examples of artificial introductions are the three mantids established in the Hawaiian Islands, two of these from the region of the Philippines and China, the other from Australia or thereabouts. One of them, the narrow-winged mantis, has also successfully entered the United States and, like the European and Chinese mantids, has become acclimated here.

Biologists or other interested people have sometimes imported eggs of exotic species, in order to observe the growth of these unusual insects in cages, and the species have been intentionally or accidentally released. Of course, each species is suited to certain weather conditions, and it usually will not survive if released in an area that is radically different from its native home in temperature, rainfall, humidity, or other basic climatic factor. In the case of the two Oriental and one European species introduced into the northeastern United States, the climate of certain areas has enabled them to multiply and become thoroughly established. Their spread in the United States is limited to what is possible by natural methods, aided by the movement of eggs or individual specimens on the part of people, and doubtless will not extend into States where winters are too severe, where desert conditions prevail, or where for other reasons the situation is not suitable.

Many insects introduced into the United States have not been so interesting or so harmless as the mantids here discussed. The Japanese beetle, European corn borer, gypsy moth, San Jose scale, and Oriental fruit moth are only a few of the outstanding pests that have reached us from abroad and that have cost the Nation almost untold expense for control work, to say nothing of personal hardship brought about by accompanying adjustments in agricultural practices or market conditions.

OVERWINTERING

In temperate regions mantids pass the winter in the egg stage, the adults all dying in fall and the new generation hatching the following spring or early in summer. Egg masses are much more noticeable during winter, because at other times they are likely to be concealed by leaves or other green vegetation. In some northeastern or Atlantic Coastal Plain States as many as 50 egg masses may be found in less than an hour in particularly favorable localities.

In warm countries with no winter season there may be a resting period or diapause in the life cycles of mantids. This is frequently correlated with dry and rainy seasons. Some desert mantids pass the diapause as nymphs. For instance, *Iris deserti* Uvarov, of Algeria and Tunisia, usually spends the diapause, which lasts 4 to 5 months, in the fifth nymphal stage.

ENEMIES

There is a high mortality among young mantids during the first few days following hatching, when they are delicate and only small insects can be captured. Hard, cold rains at this time may inflict a heavy toll, and birds may eat large numbers.

To determine which birds and mammals feed on mantids or their egg masses, I consulted the Food Habits Division of the United States

Fish and Wildlife Service, which for many years has assembled data, largely as a result of analyses of stomach contents. In their laboratory at Patuxent, Md., special analysts have learned to recognize most types of vegetable and animal food from the hard parts that digest very slowly or not at all. In the case of mantids, the head capsule, fragments of the pronotum, and pieces of the front legs do not readily digest and may be detected in stomach contents or in fecal pellets. These structures of newly hatched nymphs are poorly sclerotized or hardened, and egg masses do not leave characteristic hard parts. Consequently, in order to recognize these remains in stomachs the contents must have undergone only a small amount of digestion prior to examination.

Records are available of 34 species of North American birds that fed on mantids, of which 6 ate egg masses as well as the mantids themselves. Birds with numerous records of mantid feeding are the American crow, sparrow hawk, English sparrow, and wild turkey. The red-winged blackbird, American magpie, woodpeckers, cowbird, and several sparrows, quails, and prairie chickens are represented in the list of bird predators of mantids.

Available mammal records show that the following have eaten mantids: White-footed mouse, wood rat, prairie dog, skunk, raccoon, opossum, gray fox, red fox, and dog. All the mammals listed except the wood rat and prairie dog had eaten egg masses too. The most numerous records of feeding on mantids refer to the skunk and opossum.

In parts of the West lizards are important enemies of mantids, but in the Eastern States lizards are not nearly as prevalent, or as numerous in species. While studying range grasshoppers in the great sagebrush-covered valleys of Nevada and eastern Oregon I found a large variety of lizards, most of them very fast and agile. The minor mantid was also seen running about on the ground in both States. It is quite natural that ground-inhabiting mantids in particular, of which the minor mantid is the most widely distributed western species, should often be captured by lizards. Stomachs of certain species of Utah lizards examined by Dr. G. F. Knowlton have often contained mantid fragments.

Among insect parasites and predators of mantids, the best known are small flies and wasps that feed on mantid eggs. These insects insert their eggs into the mantid egg masses. The larvae, or grubs, of the developing parasites feed on the mantid eggs and then the resulting adult flies or wasps emerge. Mantid oöthecae collected after the season of parasite emergence sometimes show one to many tiny round holes a little smaller than the diameter of a pencil lead. These are the holes made by the emerging parasites and predators. Some parasites always emerge from the side of the egg mass, others from the

hatching area, and so on. People who place egg masses in containers in order to watch the hatching of young mantids are occasionally surprised to find that tiny parasites emerge. In some cases most or all of the mantid eggs in a single egg mass are destroyed, but in others only a very few parasites are present and a good many mantids hatch normally. In some localities very little parasitism occurs, while in others a majority of oöthecae will be found parasitized.

The best-known parasitic wasps (*Podagrion*) sometimes appear in large numbers, while others appear as occasional individuals. One of the interesting parasites (*Mantibaria manticida* Kieffer) of the European mantis in France is a tiny wasp that in the adult stage often attaches itself to adult mantids. They cling to the body of the mantid near the base of the wings, or to the lower surface of the abdomen. If the mantid is a female, and the parasite remains until she deposits eggs, the little wasp leaves the mantid and inserts its eggs into the mantid egg mass. Since the European mantis has been in the United States for many years, it is interesting to speculate that some day we may find that we also have this remarkable parasite which catches a ride with the mother of its intended victims. Its presence will be disclosed by examining mantids caught in the field for attached parasites, or by rearing parasites from egg masses and having them identified by specialists who are trained to recognize the different species.

In the spring of 1950 I confined 124 oöthecae of the Chinese mantis and 18 of the narrow-winged mantis in separate jars to see what parasites or egg predators would emerge. Four tiny flies (*Pseudogaurax anchora* (Loew)) about the size of fruit flies (*Drosophila*) were obtained, two coming from each of two Chinese-mantis oöthecae. This species is well known as a predator of mantid eggs, each larval fly feeding on one or more mantid eggs, but an interesting thing is that it preys upon the eggs of certain other insects and those of spiders, and sometimes is a scavenger in the cocoons of moths.³ Other species of *Pseudogaurax* attack both mantid and spider eggs, including those of the black-widow spider.

My rearing chambers also yielded two tiny wasps and several kinds of small flies. One of the wasps is a species known only as a parasite of scale insects, while the other has previously been found to attack other parasites. The first may have emerged from a tiny scale insect on the piece of twig to which the mantid eggs were attached. An exit hole of the second clearly showed in the egg mass, but the growing larva may have fed on some other egg parasite rather than a mantid egg. That could be determined only by careful dissections of the egg mass or by conducting better-controlled observations. The small flies included

³ The distinctions between parasite, predator, and scavenger are partly matters of technical definition, and the habits of some insects are so broad that they overlap two or more categories.

species of a family (Phoridae) that often are scavengers. During rains my cultures had become wet, and contamination by these flies probably occurred at that time. Other little flies (Itonididae) may have been in microscopic galls on the plant stems; at least they do not appear to be normal parasites of mantid eggs.

These experiences demonstrate the problems that arise in determining which insects associated with mantid eggs are true primary parasites, and the ease with which snap judgments could lead to quite incorrect conclusions regarding host-parasite relationships.

Relatively little information is available on insect predators that attack nymphs and adults of mantids. In some countries large wasps, perhaps related to those which provision their nests with cockroaches, evidently prey on mantids, but I have no data on such habits among American wasps. A very few instances have come to my attention of large parasitic flesh flies (*Sarcophaga* and *Mantidophaga*) emerging from the bodies of dying mantids. These may have been true parasites, developing from eggs or larvae attached to the mantid by the mother fly, after the manner of certain flies that parasitize grasshoppers. One case is reported (Rosewall, 1924) in which 10 fully grown maggots of *Sarcophaga* crawled from the body of an adult female of the Carolina mantis. The mantis was dying, but the observer noticed that when near death the mantid's head moved, and he discovered that a maggot had crawled through the tubular prothorax and into the head! Most of the maggots were in the abdomen. They broke out of the body, crawled into soil that was provided, pupated, and later emerged as adult flies. Other cases (Gahan, 1915) include three *Mantidophaga* maggots emerging from a Carolina mantis that previously had a hole in the side of the abdomen, suggesting that an injury may have become maggot-infested.

REARING

Many people inquire about the possibility of hatching mantids from eggs in order to watch them grow to maturity. Large mantids found outdoors late in summer may be easily kept, usually for several weeks, by confining them in a glass jar closed with screening or netting, or in a box with light entering one or more sides. Several small sticks leaning against the sides of the jar or box, to serve as supports, are important. A small potted house plant placed in a cage provides a very good environment for a mantid. House flies, blue-bottle flies, grasshoppers, and many other kinds of insects may be introduced alive into the cage to serve as food. Mealworm larvae or tiny pieces of uncooked liver, hamburger, or frankfurter may be fed by hand, if held to the insect's mouth until the food is noticed. A captive Chinese mantid I kept was fond of Japanese-beetle grubs. When a grub was held to its mouth, the mantid would begin feeding at once and usually reach

up a leg and take hold of it. Since they live in the soil, these grubs would never be eaten naturally. Freshly killed insects will be eaten, if offered on a stick or in tweezers, but mantids do not ordinarily pick up immobile bodies of insects from the floor of a cage. Water should be sprinkled on the cage each day or given the mantid with a medicine dropper.

It is more difficult to rear mantids directly from eggs, because the young are delicate and much more limited in their choice of food. Furthermore, people often have eggs that have been taken indoors during winter when the average person has no supply of suitable insects available as mantid food, so that, while the little mantids hatch by the dozens readily enough at living-room temperature, after 2 or 3 days they begin to starve rapidly. The atmosphere of many houses is too dry in winter for the mantids to do well. If a serious attempt to rear mantids to maturity from eggs is to be made, a little planning is necessary. A supply of small insects can be assured by establishing a culture of fruit flies (*Drosophila*) in jars containing fermenting bananas or other suitable fruit. Each day a few living flies are transferred to the mantid cages. Plant lice from greenhouse or other plants may also be fed to the newly hatched mantids, being transferred directly on twigs or other host plant materials. A great variety of leafhoppers and other small insects may be swept with an insect net from grass. Larger insects may be supplied as the nymphs grow. In a rearing experiment with *Stagmomantis limbata* (Hahn) it was found (Roberts, 1937b) that the consumption by one mantid during its entire life averaged over 700 insects.

Nymphs usually refuse food for the first 12 to 24 hours after hatching, and for a day immediately before and after molting. Mantids rear well at a temperature of 75° to 88° F. and with a relative humidity of 50 to 70 percent. Dryness may be partly offset by spraying water lightly from a small atomizer over the nymphs and their cage once a day. Too much water will drown them in the first nymphal stage. Unless they are overcrowded or underfed cannibalism is not common until the nymphs are half grown. After the fifth molt, only one or two nymphs should be kept in the same container, and adults should be separated if cannibalism is to be avoided. Care should be taken to avoid infestation of cages with ants; the latter are very dangerous to newly hatched mantids. A tiny mite, *Pyemotes ventricosus* (Newport), has attacked mantids in some rearing experiments (Rau and Rau, 1913).

ECONOMIC IMPORTANCE

The majority of insects normally eaten by mantids are probably injurious to gardens or other agriculture, so that mantids as a whole are beneficial insects. It is true, however, that a portion of their

prey may consist of insects that parasitize insect pests. Also, prey sometimes includes bees useful in pollinating fruit, alfalfa, or clover. Under certain circumstances, therefore, mantids may be harmful, but the good they usually do probably more than offsets the harm. The possibility of propagating them for the control of harmful insects is sometimes very appealing to people who are impressed by their tremendous appetite and conspicuous predatory habits. Because they do not eat just one kind of insect, but are rather general feeders, they cannot be directed against a specific pest, such as the Japanese beetle. Many pests, such as various kinds of borers, live inside of plant tissue, and so mantids could never attack them under natural conditions. If mantids became unusually abundant, birds might be inclined to feed on them more, or the crowding might lead to more cannibalism. For these reasons, mantids are not likely to be important in practical biological control projects.

People impressed by the value of praying mantids occasionally inquire whether there are laws protecting them. I have made an effort to determine whether any State or local ordinances have been passed to protect mantids from being molested by people, and thus far no such laws have come to my attention.

There are several beliefs or superstitions concerning the ability of mantids to kill livestock. For instance, it is often thought in the Southwestern States that a horse or cow will die if it eats a mantid or if it drinks water from a trough into which one has fallen and drowned. These beliefs are naturally unfounded, and furthermore a mantid cannot hurt a person except by the inconsequential scratching of the claws and spines when handled.

SPECIES FOUND IN THE UNITED STATES

1. Chinese mantis, *Tenodera aridifolia sinensis* Saussure:

The Chinese mantis is widespread in eastern Asia and nearby islands. It was accidentally introduced into the United States, where it was first noticed near Philadelphia in 1896. It has spread until it occurs from New Haven, Conn., to Virginia along the Atlantic coast, and at scattered localities elsewhere. In February 1949 about 200 egg masses were distributed in Warren County, Ill., and, according to Dr. R. I. Sailer, the 1950 population appeared to be increasing. I have recently learned (letter from Edwin Way Teale) that a colony has been started in California and that an Ohio dealer in biological supplies has been selling egg masses; so it is easy to see the wide opportunities that the Chinese mantis has for enlarging its distribution. It is our largest species, usually being 3 to 4 inches in over-all length when the wings are folded over the back. The egg mass is sometimes as much as $1\frac{1}{2}$ inches long and usually an inch or nearly an inch in diameter.

2. Narrow-winged mantis, *Tenodera angustipennis* Saussure:

This is a close relative of the foregoing species, from which it differs in being smaller and less robust and in having less dark color on the hind wings. The egg mass is elongate, usually an inch to an inch and a half long, and seldom over one-half inch in diameter. This mantid is also Asiatic in origin. It was noticed near Aberdeen, Md., as early as 1926 but was not noted by a published record until 1933. Prior to that time adults had been supposed by a number of people who found them to be small individuals of the Chinese mantis, though the eggs were puzzling and not satisfactorily explained. It was first reported (Jones, 1933) from the region of New Castle, Del., and adjacent Maryland. It is now well established from New York City to Virginia. Attempts to establish the narrow-winged mantis at Stamford, Conn., have been unsuccessful (letter from Dr. Stanley W. Bromley).

In some localities this species is apparently fully as common as the Chinese mantis, but at Falls Church, Va., I have found more of the latter, both of egg masses and the mantids themselves. However, egg masses of the narrow-winged species are seldom found on weeds such as goldenrod but occur attached lengthwise to the surface of woody stems or twigs that usually are at least as large in diameter as the width of an egg mass. In contrast, the chunky oöthecae of the Chinese mantis occur both on small weeds, the stems of which they often enclose, and on the twigs of shrubs and trees. A weed field having few shrubs or trees will therefore offer the Chinese mantis much better opportunities for oviposition.

At Falls Church, Va., eggs of the Chinese mantis hatched from May 27 to June 26, the majority during the first 10 days of June. As oöthecae of the narrow-winged species yielded their young between June 17 and 27, the average hatching date is probably 1 to 2 weeks later than for the larger species.

3. European mantis, *Mantis religiosa* Linnaeus:

This is a widespread species of northern Africa, southern Europe, and temperate Asia. It appeared at Rochester, N. Y., in 1899, probably the result of eggs being introduced on nursery stock. Soon after the discovery at Rochester, a fine account (Slingerland, 1900) of the species was prepared. Adults are about 2 to 2½ inches long, and the wings cover the abdomen when folded. Egg masses are rather more bulky than those of the Carolina mantis, but less so than those of the Chinese mantis and differently shaped.

For some years the European mantis has been well established in western New York and southern Ontario, where the climate is less severe than in northern New England. It was noticed in 1949 at

several localities in Vermont and Massachusetts, and in 1950 it again occurred abundantly at several New England localities, and was found near Albany, N. Y. In 1950 I was surprised to find it at the summit and on the slopes of Mount Greylock, the highest peak in southern New England, which is so boreal that the wingless White Mountain grasshopper (*Zubovskya glacialis glacialis* (Scudder)) lives there. Can it be that 50 years have been required for the mantid to spread by natural means from the Rochester, N. Y., area; or has climate, which apparently limited the eastern spread, moderated and permitted this mantid to move quickly into New England areas formerly closed to it? An inquiry to the Weather Bureau disclosed that at Pittsfield, near Mount Greylock, one of the important weather stations of western Massachusetts, the average temperature during the winter of 1948-49 was higher than any in the station's history. In the winter of 1949-50 it was also high, well above average. This certainly suggests that mild climate has been partly responsible for the spread of the European mantis; also that a very severe winter may yet eliminate it as a naturalized New England insect.

I further learned that a biology professor near Boston had released the mantid during recent years, probably accounting for some current records from eastern Massachusetts, and that truckers had brought loads of dried hay from New York State into western Massachusetts and perhaps to other sections of New England. In hayfields at Cummington, Mass., I found the species abundant. The logical conclusion is that if the imported hay came from New York areas where the mantid was established, then egg masses could easily have been brought to Massachusetts. In other words, climatic changes alone probably were not entirely responsible for the expanded distribution, but, instead, a combination of climate and artificial introductions.

4. Carolina mantis, *Stagmomantis carolina* (Johansson), and related species:

This is the best-known native mantid of the Eastern States. It occurs from Pennsylvania across the Middle West to Colorado and south into Mexico. There has been doubt as to whether the insect occurred in New Jersey, but inasmuch as Teale (1950) has reported its occurrence around Baldwin, Long Island, perhaps a northeastern extension has recently been favored by mild winters, and the species may prove to occur in New Jersey. Males of the Carolina mantis are much more slender than the females. Wings of the latter usually are noticeably shorter than the abdomen, and there is little if any flight except by the males. Over-all body length is usually $1\frac{1}{2}$ to 2 inches. Egg masses usually are scarcely more than an inch long and half an inch or somewhat more in diameter.

A second species of *Stagmomantis*, *S. floridensis* Davis, occurs in Florida. In the Southwestern States three others occur: *S. californica* Rehn and Hebard; *S. gracilipes* Rehn; *S. limbata* (Hahn). All are closely related to the Carolina mantis, differing in size, color, and technical structural details. Studies of the egg masses deposited in Texas by species of *Stagmomantis* (Breland and Dobson, 1947) showed that apparently a species additional to any now recorded for the United States occurs there. Three species, *limbata*, *carolina*, and *californica*, already occur in Texas, the egg masses being well known, while *gracilipes* occurs west of the zone where the strange eggs have been found. Perhaps the adults reared from such eggs will eventually be found to represent one of the Mexican or Central American species, since the genus *Stagmomantis* is richly represented south of the United States.

5. Minor mantis, *Litaneutria minor* (Scudder) :

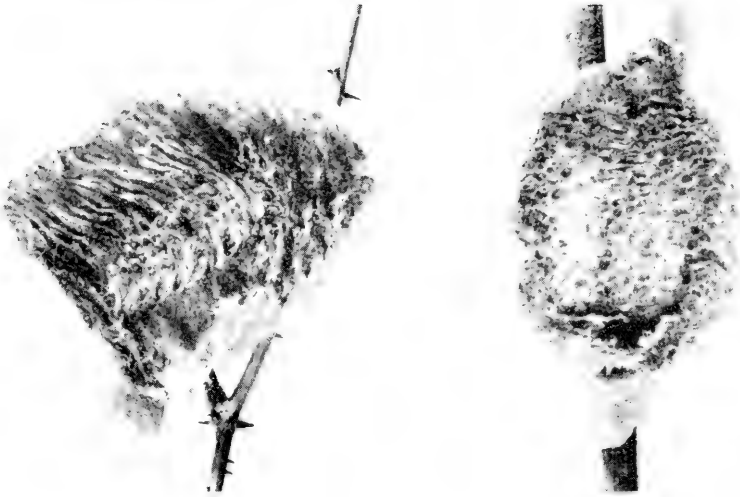
This is the most widespread species of the West, occurring from North Dakota and central Texas to British Columbia and south into Mexico. Adults normally do not exceed $1\frac{1}{4}$ inches in length, and the color is light buff to dark brown. Males are usually fully winged, but wings of the female seldom cover more than one-third of the abdomen. This mantid is most often found on the ground, but sometimes it occurs on vegetation. Egg masses are small, averaging about one-fourth inch long, more or less rectangular with rounded corners. In Texas a partial second generation of the minor mantid occurs (Roberts, 1937a). Part of the eggs laid by the summer generation hatch that fall, but the nymphs do not usually reach maturity.

6. Unicorn mantids:

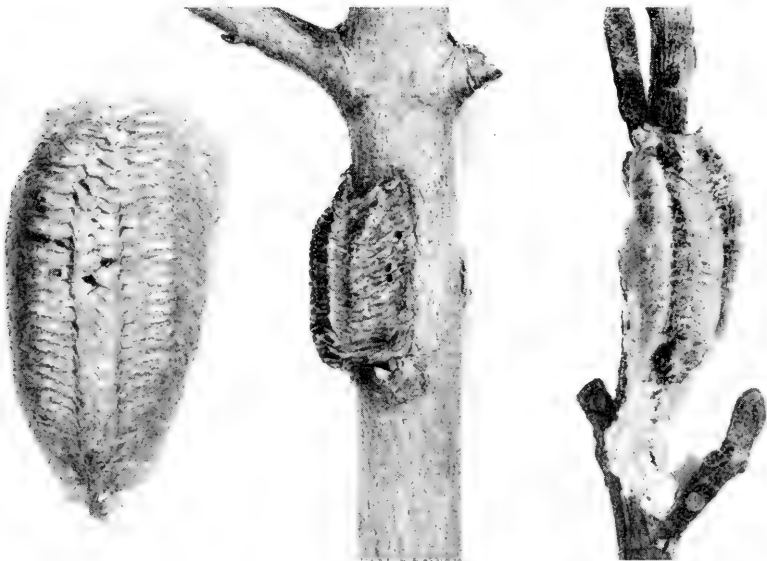
There are two species of these striking mantids in the United States. Both have a conspicuous split horn extending forward from between the eyes, and there are usually two dark bars across each green front wing. Body length (including folded wings) is about $2\frac{1}{2}$ to 3 inches. One of the two, *Phylloteles chlorophaea* (Blanchard), is widespread in Central America but occurs within our borders only in southeastern Texas. The other, *Pseudoteles arizonae* Hebard, is quite rare and known only in Arizona. It differs from the former species by having swollen lobes projecting from the middle and hind legs.

7. Grizzled mantis, *Gonatista grisea* (Fabricius) :

The grizzled mantis is endowed with excellent camouflage, the body and front wings usually being mottled with green and brown, thus enabling the insect to escape being seen except when it moves. The species is proportionally broader than our other mantids of the same



1. Two egg masses of Chinese mantis, *Tenodera aridifolia sinensis*, sectioned to show structure. Left: Lengthwise section cut from front, showing side view of eggs in center and parallel emergence passageways leading upward and to the left. Right: Lengthwise section cut from side, showing front view of eggs surrounded by fibrous protective material. $\times 1\frac{1}{4}$.

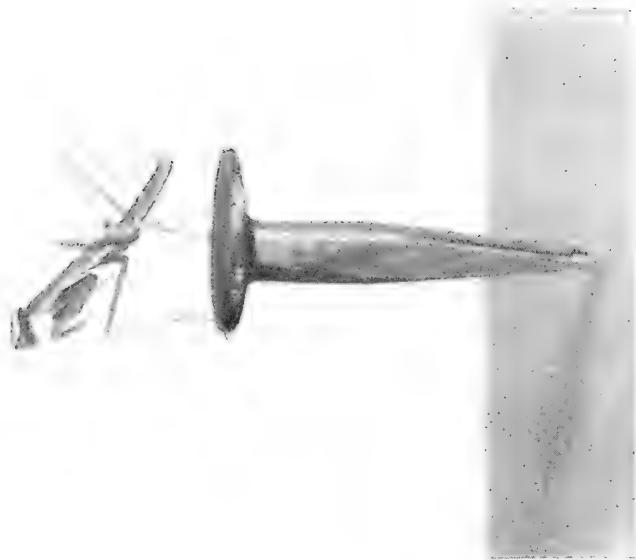


2. Egg masses of three common mantids. Left: European mantis, *Mantis religiosa*, removed from a board. Center: Carolina mantis, *Stagmomantis carolina*, with parasite emergence holes on side. Right: Narrow-winged mantis, *Tenodera angustipennis*, showing the characteristic elongate streaks of darker color. $\times 1\frac{1}{4}$.

(Photographs by Floyd B. Kestner.)

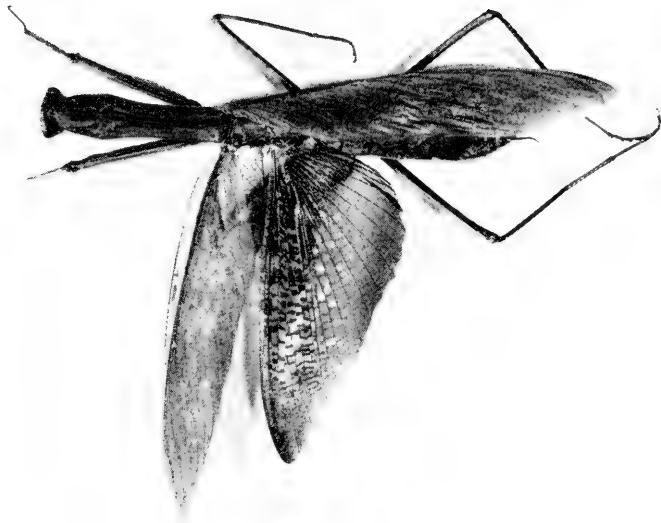


1. The act of hatching in Chinese mantis. Nymphs are emerging from hatching area and are hanging downward as intermediate molt is in progress. Enlarged.



2. A nymph of the Chinese mantis, less than an hour old, standing on a carpet tack. Enlarged.

(Photographs by Edwin Way Teate.)

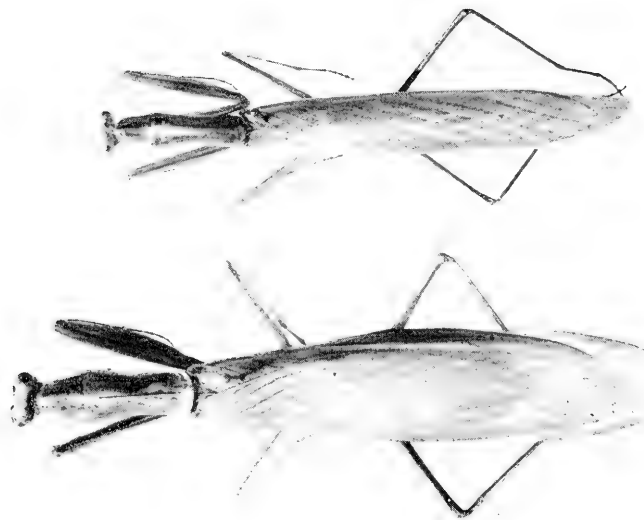


1. Adult female of Chinese mantis, with left wings spread to display shape and color pattern. $\times \frac{3}{4}$

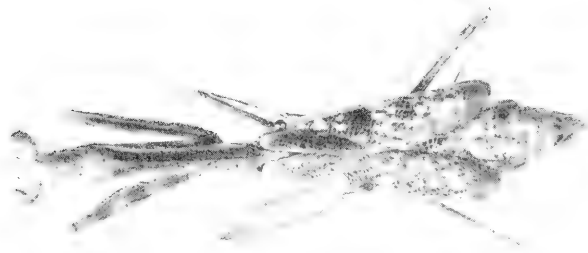


2. Adult female of narrow-winged mantis, *Tenodera angustipennis*. Hind wing is slenderer than in Chinese mantis and not so heavily blotched with color. Slightly less than natural size.

(Specimens from Washington, D. C. Photographs by Floyd B. Kestner.)

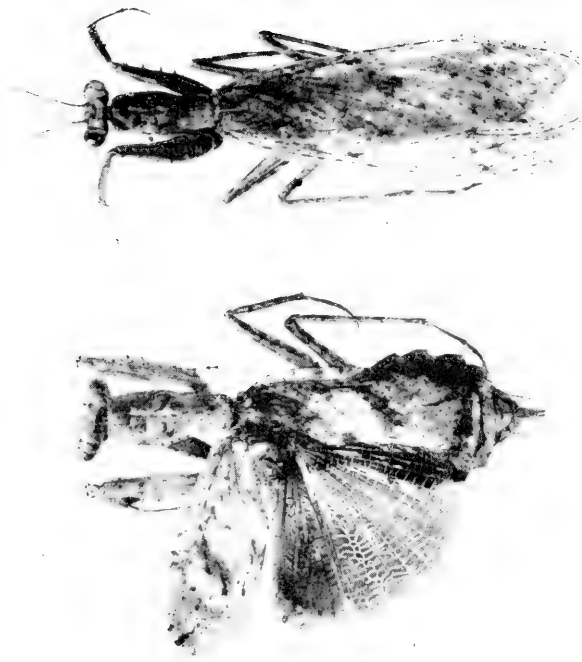


1. European mantis. Left, female; right, male. Both of these specimens are green, though some are brown. (Specimens from Massachusetts.) $\times 1\frac{1}{4}$.

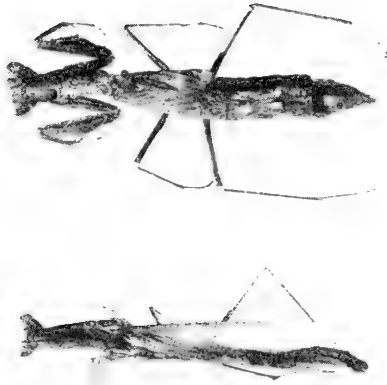


2. Carolina mantis. Left, female from North Carolina; right, male from Washington, D. C. Predominantly dark specimens illustrated, with some mottling in female. Specimens of light green color often occur. $\times 1\frac{1}{2}$.

(Photographs by Floyd B. Kestner.)

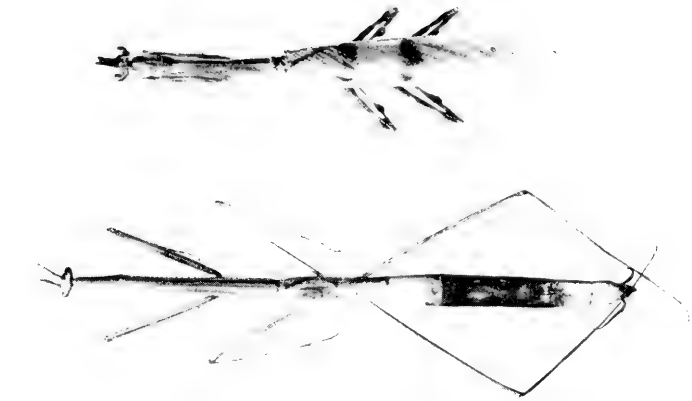


1. Grizzled mantis, *Gonatista grisea*. Left, female; right, male. Hind wings of female are bluish black; those of male only lightly spotted. (Specimens from Florida.) $\times 1\frac{1}{2}$.



2. Minor mantis, *Latanorobita minor*. Left, male; right, female. The dark spot on the hind wing of males is variable, sometimes absent. Short wings are characteristic of females. (Specimens from Arizona.) $\times 1\frac{1}{2}$.

(Photographs by Floyd B. Kestner.)



1. Left: *Branneria borealis*, female, a southeastern mantid of which no males have been found. It has very short vestigial wings. (Specimens from Louisiana.) Right: A unicorn mantid, *Pseudorates arizonae*, male. (Specimen from Arizona.) $\times \frac{5}{4}$.



2. Left: *Thespertia graminis*, male. Front legs extend forward beneath the head in this specimen, and abdomen is missing. Females of this species have no wings. Right: A male of the species of *Mantoida* in Florida, the smallest mantid living in the United States. Note the very short thorax. (Specimens from Florida.) $\times 1\frac{1}{2}$. (Photographs by Floyd B. Kestner.)

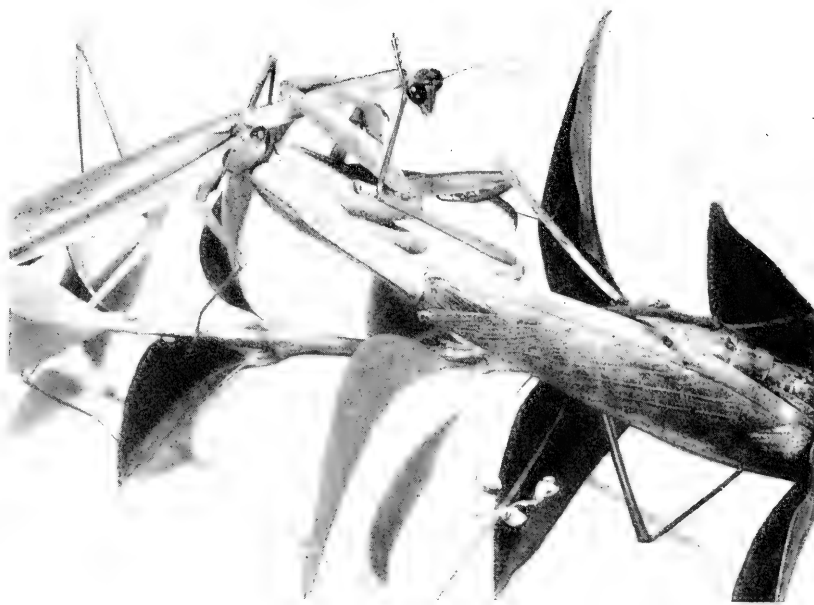


1. Head of *Thesprotia graminis*. Female, one antenna missing, other incomplete. Note the shape of the eyes and face in comparison with *Yersiniops* below. (Specimen from Florida.) $\times 15$.



2. Head of *Yersiniops solitarium*. Male, showing characteristic conical eyes. Parts of the front legs are included. (Specimen from New Mexico.) $\times 15$.

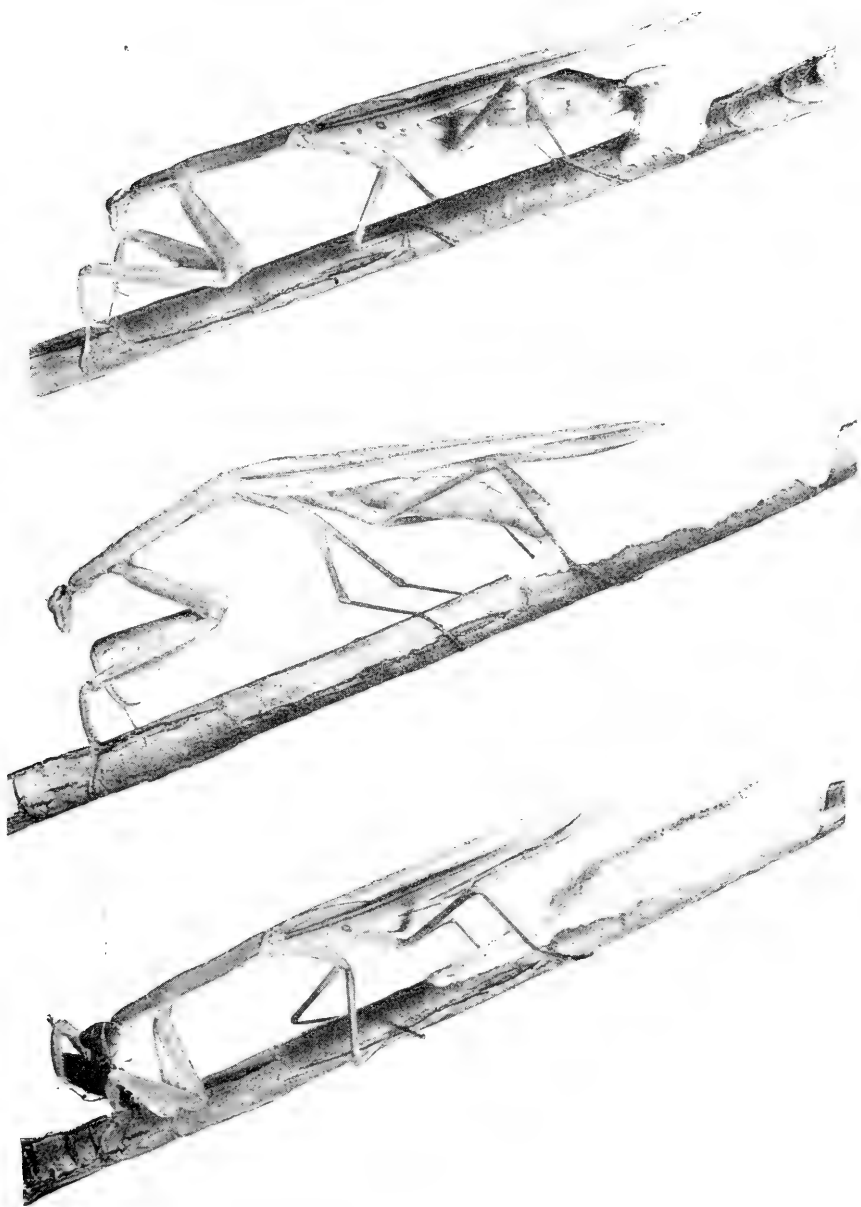
(Photographs by Floyd B. Kestner.)



1. A female of the Chinese mantis attacking a male by seizing him and starting to bite into the thorax. Slightly reduced.
(Photographs by Edwin Way Teale.)



2. Dinner completed, the female contemplates the wings and other remains of her mate. Slightly reduced—more than figure 1.



EGG LAYING BY A NARROW-WINGED MANTIS

Three views of a female, showing (upper) the beginning of oviposition, (center) oviposition nearly completed, and (lower) the finished egg mass with the female eating a fly before moving elsewhere. Approximately natural size. (Photographs by John G. Pitkin.)



length. It occurs in the Southeast, where it extends from Florida to South Carolina. The genus *Gonatista* is primarily West Indian, and *grisea* occurs in Cuba as well as in the United States. Several related species live in the West Indies.

8. Other mantids:

One of the distinctive southern species is *Brunneria borealis* Scudder. Only females have been found, though there are several related South American species of which males have been described. Many groups of insects include certain species that lay fertile eggs in the complete absence of males (parthenogenesis), and this is a notable example in the Mantidae. Our species is green, about $2\frac{1}{2}$ to $3\frac{1}{2}$ inches long, very slender, and with only vestiges of wings. It occurs from North Carolina to Texas. Its egg mass, about one-half to three-fourths inch long, is characterized by a distinct point at the lower end. At hatching time, all nymphs emerge from this point, rather than from a broad hatching area (Breland and Dobson, 1947).

A species of the genus *Mantoida* occurs in Florida, and for many years it has been supposed by entomologists to be *Mantoida maya* Saussure and Zehntner. The original habitat of *maya*, from which the type specimen was obtained, is Yucatán. Now it is somewhat uncertain whether the Floridian form may not be a distinct species, peculiar to the United States, though, of course, closely related to the one in Yucatán. This is another of the problems involving native mantids that deserve careful attention. Our *Mantoida* is a rare species, evidently most active at night and hunting to a large extent on the ground, these habits probably explaining in some measure why few people have seen it.

Five other species of mantids are known from the Southern and Central States, including the Southwest. All are small and of inconspicuous brown coloration, which blends with the grasses and shrubs among which they live. Two of them, *Yersiniops solitarium* (Scudder) and *Y. sophronicum* (Rehn and Hebard), are distinguished from our other mantids by the shape of the compound eyes, which are produced upward into sharp, conical points. These closely related species live in the Southwest. They usually occur on the ground and run rapidly, and in the case of *solitarium*, exceptional abilities in leaping are also characteristic.

A very delicate, extremely slender mantid found fairly commonly among grasses in Florida, even in winter, is *Thesprotia graminis* (Scudder). It also occurs in Georgia and along the Gulf coast as far west as Mississippi. The remaining species are *Oligonicella scudderi* (Saussure) and *O. mexicanus* (Saussure and Zehntner).

They are intermediate in relative slenderness between *Thesprotia* and the minor mantid. *Oligonicella scudderi* is widespread in the Southeast, extends north on the Great Plains to Nebraska, and inhabits all Texas except the extreme western and southern portions. In the southern extremity of its range, it is believed to have two generations a year (Hebard, 1943). Its congener, *mexicanus*, occupies a wide area in Mexico and northern Central America but in the United States occurs primarily in southeastern Arizona (Hebard, 1943).

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MAN'S DISORDER OF NATURE'S DESIGN IN THE GREAT PLAINS¹

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[With 4 plates]

When man came to the shores of our continent he was confronted with an empire of great expanse and diversity. Animal life, including the American Indian, secured its subsistence mostly from native plants and animals. Our earliest settlers on the Atlantic coast immediately began to clear the ground for cultivation, and as population moved westward, the practice of cultivating the soil moved likewise. It took many years, however, to reach the high plains of western Kansas. Wheat production seemed not to reach its maximum relative importance as a farm crop in the United States until it was grown on soils formerly occupied by prairie vegetation. This crop provided an ever-increasing supply of wheat flour for making bread, but "man does not live by bread alone"—he needs a beefsteak occasionally. If man today were like Nebuchadnezzar of old, it would not be necessary for him to obtain by proxy his share of the vast amount of energy produced in the vegetation of our grasslands (Sampson, 1923). We have advanced beyond the stage of our ancient forefathers, however, and consequently we are confronted with the necessity of growing livestock in order to provide a portion of our daily diet. But livestock does not live by corn alone. It has long been recognized that the grasslands of America and elsewhere are indispensable to economic livestock production.

If grasslands are as indispensable as we have been told, perhaps it would be of interest to look into the origin of the prairies. According to authorities on the subject, many millions of years ago the area now occupied by the Great Plains of North America was a vast body of water (Harvey, 1908). The marine fossils embedded in strata of limestone, under what is now the Great Plains, attest this fact. From the close of Carboniferous time to lower Cretaceous time, the area was mostly land and occupied by certain types of ferns and conifers (Gleason, 1922). This type of vegetation evidently prevailed for many millions of years. During middle and late Cretaceous time the region was again invaded by a shallow sea, and

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following its withdrawal there occurred the uplift of the Rocky Mountains on the west. These mountains, according to authorities, intercepted the moisture-laden winds from the Pacific Ocean and restricted the rainfall on the lands immediately east of them to moisture derived from the Gulf of Mexico. Gradual decrease in precipitation resulted ultimately in a grassy type of vegetation in this area. It is believed that this grassland type of vegetation has occupied parts of the Great Plains continuously for millions of years, and that vast armlike projections of grassland have pushed out many times in several directions and withdrawn again when changes in climate occurred.

Millions of years after the formation of the mountains on the west, there occurred a series of events that exerted a significant influence upon the vegetation of the Great Plains. During the later Tertiary, gradual cooling of the climate in higher latitudes caused significant changes in the environment, which resulted in the disappearance of subtropical species of plants from north and west America. Apparently a distinct separation developed between the northern flora, predominantly gymnosperms, and the southern flora which was controlled by angiosperms. These two primarily aborescent types (in addition to the grasslands) have maintained their identity in North America since preglacial times.

As cooling of the higher latitudes continued, the Tertiary period came to a close and it was followed by the period of glaciers. It is not the purpose of this paper to describe in any detail the cause or the extent of glacial periods, but rather to consider briefly their effect upon the vegetation in the wake of their advance. As the ice moved down from the north there was started a migration southward of all living forms. Belts of vegetative types such as tundra, bog scrub, coniferous forest, and deciduous forest were usually maintained through the east and middle west as they moved southward. The width of each belt of vegetation, however, varied with topography. Farther west the treeless plains region was covered by prairie vegetation. This vast area of level land probably was bordered on the north by a broad belt of tundra.

With retreat of the ice, the new bare glacial soil was naturally first invaded by the mosses and lichens of the tundra. After further retreat of the ice the climate became more suitable for plant growth, and as a consequence the belts of vegetation proceeded northward from the position they occupied at the southernmost advance of the glaciers. In the east the succession northward was in the order of tundra, bog scrub, and conifers. The prairie grasses from the plains region, however, not only invaded the immediate adjoining tundra to the north but also succeeded in penetrating the glaciated regions of

the middle west. These grasses advanced slowly toward the east and northeast, proceeding as a wedge-shaped extension between the coniferous vegetation on the north and the deciduous forests on the south. The grasses apparently displaced the deciduous forests in the drier locations as far east as Ohio (Woodard, 1924). One explanation of this unusual phenomenon of prairie succeeding the forest is that a xerothermic period began during the Wisconsin glaciation and persisted through the post-Wisconsin glacial retreat. Because of the dry period, the advance of the deciduous forest from the south was delayed, but the more humid grasses and their associates moved northward and came in contact with the prairie vegetation that moved in from the west. Thus the bluestems, the Indian grass, and the panic grasses came to be associated with buffalo grass, the grama grasses, and other xeric forms from the west. This association evidently represents the farthest eastward general advance of the prairie vegetation of which we have any record.

At a later period amelioration of the climate occurred which gradually ended the xerothermic period. As a consequence, the oaks, hickories, elms, ashes, cottonwoods, maples, etc., of the deciduous forests followed the retreating grasses in a westward direction. As the short grasses retreated westward, they took with them their "cousins" from the south, and upon their return to the high plains the more xeric grasses came to occupy the drier positions, whereas the grasses of the more humid south became established on the eastern border of the grassland formation and along streams and more favored positions westward.

There is no attempt here made to discuss in any detail the source of the material that went into the formation of the soils of the Great Plains except to mention in passing that some of the material was brought in by glaciers, some by winds, some by water, and some of the soils were formed in situ from existing rocks. Soil is not just a mass of inert mineral and organic material. It must have both of these materials, but in addition, if it is a good soil, it is necessary to have soil solution, soil atmosphere, and an abundance of soil organisms. The interaction of all these constituents working through centuries of time has resulted in a soil that is one of the most fertile known to mankind. It was the interaction of climate, plants, and soils that brought plants and soils to their present native state of development.

The prairie vegetation is particularly well adapted to the production and protection of a deep fertile soil. The roots of many of our grasses penetrate the soil to a depth of 5 to 8 feet depending in part upon species of grass and in part upon the type of soil in which they grow. Many of the broad-leaved herbaceous plants, such as wild alfalfa, extend their roots somewhat deeper than do the grasses.

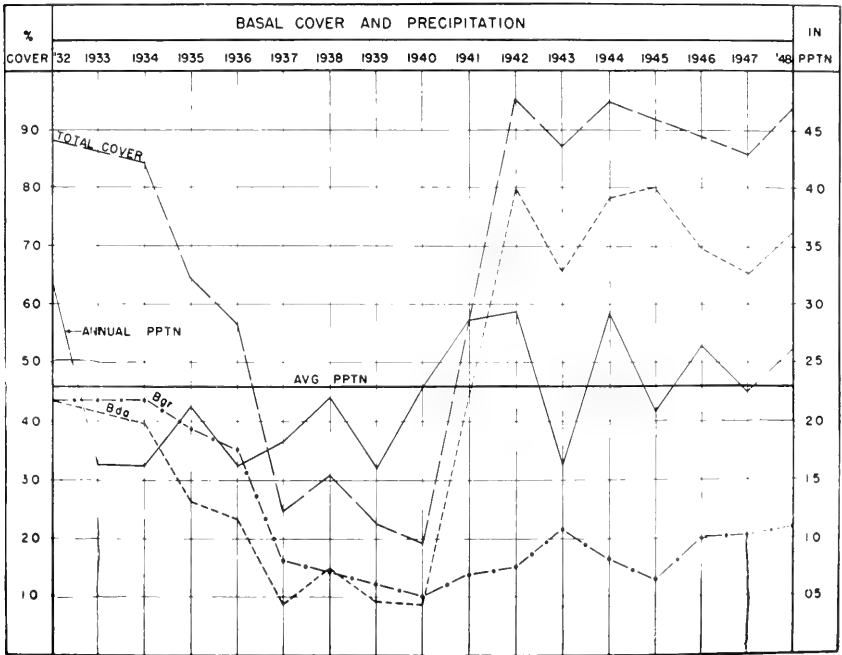
Under these circumstances soil moisture and nutrients are secured from different levels, reducing the amount of competition among the various species. There is considerable replacement of roots each year—the dead roots increasing the supply of organic matter in the soil. Under good range management even the litter and debris on the surface gradually becomes incorporated into the soil.

In addition to being a first-rate soil builder, a good cover of grass also ranks near the top as a soil protector. As the raindrops strike the prairie vegetation the force is broken, and the shattered raindrops run down the blades and stems of the vegetation where the accumulated water is held long enough for most of it to enter the soil. During downpours the clear excess water slowly runs away leaving the soil held firmly in place by the vegetation.

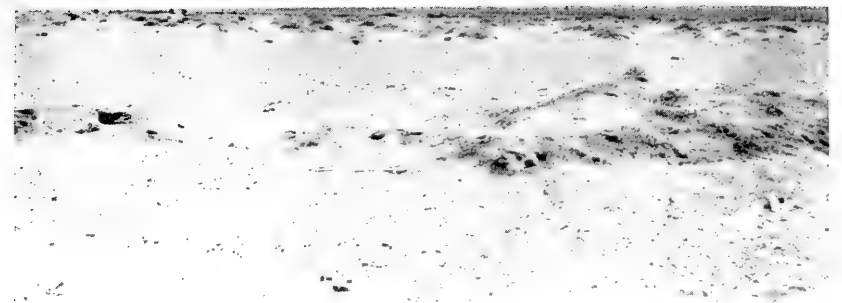
There is a close relationship between the type of climate, vegetation, and soil found in any region, and it appears safe to assume that to understand our climate we must understand our vegetation and the soils this plant growth produces. There is just one major reason why the grasses invaded as far east as Ohio in past geologic ages—it was climate. There is just one major reason why the forest did not replace the grasses in the high plains—it was climate. Thus we may study our native vegetation and predict with a considerable degree of accuracy the type of climate that produced the vegetation and the type of soil in which the vegetation is growing.

The herbaceous type of vegetation in the Great Plains is best adapted to the extremes in climate that occur. Cycles of drought, hot desiccating winds of high velocity, prairie fires, tornadoes, hail storms, and severe winters are all common to the plains region, but through all these, the prairies have prevailed. There are times each season, however, when prairie vegetation does not receive sufficient moisture for growth, and, therefore, much of it is forced into dormancy. The process of going into dormancy and out again may occur several times in one season; this is a common experience for the short grasses of the high plains (Albertson and Weaver, 1942). During extreme adversity in the past, our native prairie doubtless suffered greatly, but upon the advent of more favorable conditions replacement of the former cover was rapid (Albertson and Weaver, 1944b). Dust storms have been known to occur earlier than those that visited us during the thirties. The wind-formed soils extending from the Mississippi Valley westward and covering much of northwestern Kansas illustrate this fact (Lyon and Buckman, 1943). Even during the last half of the nineteenth century our early settlers reported numerous "dusters" (Malin, 1946).

When the early explorers came through the plains region they found many of the plants that abound today in our native prairies; for



1. AVERAGE AND ANNUAL PRECIPITATION, TOTAL PERCENT BASAL COVER OF BLUE GRAMA AND BUFFALO GRASS ON A WELL-MANAGED RANGE AT HAYS, KANS.



2. MOUNDS OF DRIFTED SOIL ON AN OVERGRAZED RANGE IN SOUTHWEST KANSAS IN 1939

Nearly all native vegetation was killed.



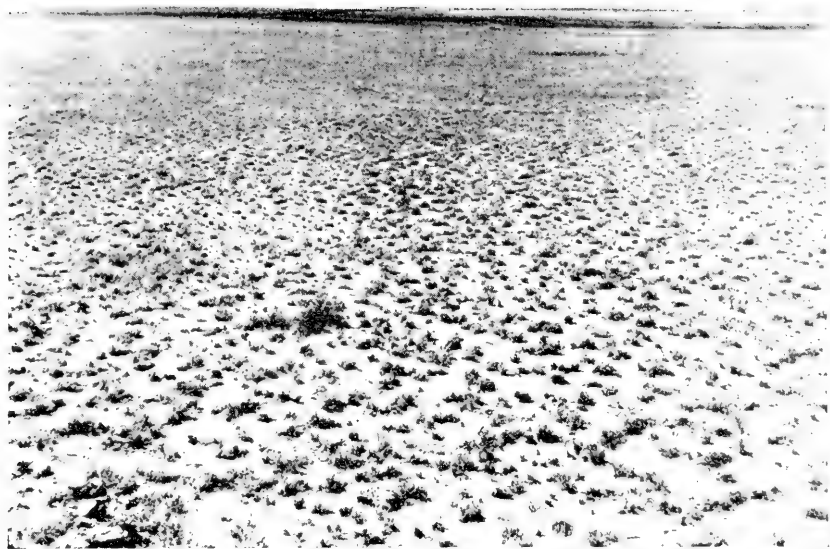
1. SAME AREA AS SHOWN IN PLATE 1, FIGURE 2

Nothing but annual weeds were growing here when photographed in 1944.



2. RANGE NEAR WINONA, KANS., IN SPRING OF 1941

Blue grama and buffalo grass (light areas) comprised 5 percent of cover of native vegetation. Remaining part of area was bare or occupied by annual weeds.



1. A WELL-MANAGED PASTURE AT DIGHTON, KANS., IN 1939
The cover of blue grama and buffalo grass was 20 percent.



2. SAME AREA AS SHOWN IN FIGURE 1, ABOVE
Replacement of cover was nearly complete in 1942.



1. A WELL-MANAGED RANGE AT NESS CITY, KANS., IN 1946
Yield of grass was 1,800 pounds per acre.



2. A HEAVILY GRAZED RANGE IN 1946

Located within 1 mile of the pasture shown in figure 1, above. Yield of grass was 900 pounds per acre.

example, Frémont, in 1842, reports the presence of the following plants in or near Kansas:

Leadplant.....	<i>Amorpha canescens.</i>
Willow.....	<i>Salix longifolia.</i>
Prairie sage.....	<i>Artemisia</i> spp.
Milkweed.....	<i>Asclepias tuberosa.</i>
Thistle.....	<i>Carduus</i> spp.
Sunflower.....	<i>Helianthus</i> spp.
Buffalo grass.....	<i>Buchloe dactyloides.</i>
Wild alfalfa.....	<i>Psoralea floribunda.</i>
Sensitive-brier.....	<i>Morongia uncinata.</i>
Gaillardia.....	<i>Gaillardia</i> spp.
Evening primrose.....	<i>Gaura coccinea.</i>

The plants referred to by Frémont were doubtless important as a part of our prairie vegetation many centuries past.

The author of this paper remembers fairly distinctly the conditions that existed nearly 50 years ago. The vast majority of the land was native prairie. It was neither broken for cultivation nor overgrazed by livestock. The hilltops were occupied by short grasses and low-growing broad-leaved herbaceous plants. Many of the hills were dotted with bunches of little bluestem, and in the favored areas, such as buffalo wallows, side oats grama and big bluestem were common. The hillsides were occupied primarily by big and little bluestem, side oats grama, Indian grass, and panic grass. All but the little bluestem and side oats grama were dominant on the lowlands. At this time, most of the land was open range and the livestock owned by the pioneers roamed as they wished along the streams and over the highlands. Occasionally small areas had been broken for cultivation. It is the change from the condition as it existed a half century ago to the present state that has become our principal difficulty. As the population increased, more land for cultivation was necessary. Increase in the cultivated area reduced the amount of native rangeland at a time when there occurred an increase in the number of livestock; hence a gradually increasing number of livestock was forced to graze on a gradually decreasing area of native rangeland. These effects have been the cause of at least two problems. The first is proper management of our cultivated land so that dusting of grasslands is reduced to a minimum. Research and leadership from our experiment stations and Federal agencies have assisted greatly in bringing to our attention better methods for utilizing and conserving our cultivated soils. The second problem with which we are confronted is the proper management of our rangeland in order to secure maximum use with a minimum of deterioration.

We have said that the native vegetation of the high plains is better adapted to the prevailing environmental conditions than is any other type of vegetation; that is why it is dominant. This statement does

not mean, however, that growth is luxuriant regardless of the season. During cycles of drought, it is only natural to assume that vegetation would adjust itself to drought conditions. Increment of growth during dry seasons would naturally be less. Seed production would be gradually decreased as would also basal cover. Even root development would doubtless be modified greatly. Recovery, however, would occur over a relatively short period of time. The greatest destruction of our rangeland has occurred when the impact of overutilization of rangeland and poor tillage practices of our cultivated soil have been added to the impact of unfavorable climatic conditions. The early pioneers were not confronted with overutilization because as grass became scarce in one area the livestock naturally moved to another area on the free range where utilization had been less intense. Under these conditions it was only natural to draw the conclusion that grasslands were not expendable—that they came into existence through a long period of adversity and nothing that man could do would destroy them.

Research on rangeland in the Great Plains has been limited mostly to the present generation; in fact, most of it has been done during the past 20 years. Several members of the botany staff of Fort Hays Kansas State College claim western Kansas as their "native habitat." They have watched the prairies gradually deteriorate under the influence of overutilization, or have seen their complete destruction as they were put under cultivation. It therefore became obvious that more information was needed in order to know more fully how we might maintain our prairies under high production at the same time they were being utilized by livestock and, more recently, how to regrass much of our worn-out cultivated land. In the late twenties and early thirties a program of study was initiated at Fort Hays Kansas State College and has continued unbroken since that time. Fortunately, from 1927 to 1932 inclusive, precipitation at Hays and at other locations in the high plains was considerably above normal. This condition made it possible to lay out research and to obtain initial data at a time when our prairies were at a maximum of development. Areas were set aside in 1932 in order to determine what and how much vegetation occupied different topographic locations (Albertson, 1937). More recently, other studies have been inaugurated throughout western Kansas, particularly in the southwest (Albertson, 1941, 1942). Many of these areas have since been plowed up and planted to wheat—a practice that has been going forward at an alarming rate in western Kansas and eastern Colorado during the past few years.

Research on the prairies during past years has revealed some striking facts. The first significant reaction of prairie vegetation to drought is decreased growth. As drought continues and becomes

more intense, that portion of vegetation least adapted to adversity dies, thus leaving an open cover. Further drought adds to the openness of the cover until finally run-off of rain water is materially increased, causing soil erosion and further depletion of soil moisture. This cycle of events continues to make the situation more and more critical, especially if deficient precipitation extends over a long period of time and over a large area. When the effect of overutilization is added to that of drought, the result, indeed, is very significant.

A few figures on cover and yield in relation to degree of utilization and amount of precipitation might be used to illustrate this principle. In 1932, which was the close of a 6-year period of above-normal precipitation at Hays, Kans., the basal cover on a well-managed short-grass pasture averaged nearly 90 percent of the total area (pl. 1, fig. 1). The decrease in precipitation following 1932 was extremely abrupt but it took 2 years of drought to produce a significant decrease in the cover, and by 1937 the blanket of vegetation had been reduced to 25 percent, and in 1940, when the drought closed, the cover was only 20 percent. With the return of sufficient soil moisture the cover was quickly restored because of the phenomenally rapid growth of buffalo grass.

On an adjacent heavily grazed range, the lowest cover of 2.6 percent was reached in 1936. In various locations in southwest Kansas where dusting and utilization were severe, the last vestige of vegetation was often removed and even today some of the rangeland has the appearance of weedy cultivated fields (pl. 1, fig. 2, and pl. 2). Other ranges in southwest Kansas that were more fortunate in regard to degree of utilization and dusting have long since regained their predrought cover (pl. 3).

The question often asked is "How much do short-grass pastures produce each year?" Obviously there is no *one* answer. Production of grass usually varies directly with amount of soil moisture and inversely with production of weeds. It should be stated, however, that a cover of weeds is preferable to no cover, for weeds protect the soil from erosion in addition to furnishing considerable food for livestock. In 1940 a No. 1 pasture at Hays yielded nearly 1,400 pounds per acre of grass but only 400 pounds per acre of weeds (Albertson and Weaver, 1944a). A poorly managed pasture produced only 133 pounds of grass per acre but the weed crop was over 1 ton per acre. Farther west than Hays there were fewer good pastures, and in 1940 even the best of these yielded less than 200 pounds of grass but nearly 1,500 pounds of weeds.

In 1941 the best pastures at Hays increased in yield considerably but the better ones westward often increased tenfold or more. The poor pastures, however, failed to make significant gains except in the

production of weeds. It seemed evident that when a remnant of vegetation remained at the close of drought, restoration of cover was extremely rapid and the yield for some time after restoration even exceeded that on the better pastures where the cover suffered less during drought. Possibly this result was due in part at least to a more vigorous new cover on a soil that had rested for a few years.

In 1946 a well-managed pasture at Ness City, Kans., yielded 1,800 pounds per acre but a nearby heavily grazed area produced only half this amount (pl. 4). Five areas near Collyer, Kans., were studied during the summer of 1946 (Tomanek, 1948). These ranges differed mainly in the intensity of utilization during 15 years preceding the period of study. The ungrazed pasture produced approximately 2,500 pounds per acre as compared to 4,000 pounds on a well-managed range and only 1,800 pounds on a heavily grazed area. These data indicate that heavy utilization reduces the yield by 50 percent and that grazing too lightly also decreases production.

A 5-year study on a short-grass pasture near Hays was initiated in 1942 to simulate different intensities of grazing by clipping at different heights and at different intervals. It was discovered in this study that approximately 50 percent of the grass could be left on the area and in 5 years the amount removed from these locations nearly equaled total production on the areas where all growth was harvested. Root development under these treatments also was significantly different. Roots under nonuse and moderate use were nearly the same, but under heavy clipping the roots were not only finer and less in number per unit area but also their depth of penetration into the soil was significantly less.

Life histories of important grasses of the Great Plains have been studied in order to know the best sources of grass seed for reseeding cultivated land (Riegel, 1941; Webb, 1941; Hopkins, 1941). It seemed wise to revegetate some 500 acres of cultivated land on the college farm, and while doing this, basic studies have been made on methods of seedbed preparation, methods of seeding, rate of growth, and yield (Riegel, 1940).

In order to manage our rangeland properly, it seemed desirable to have more information on the time of the season when growth occurred. It was surprising to some to find that as much as 70 percent of the total growth in one season occurred before July.

Numerous studies indicate that cattle, for example, enjoy variety in their range diet just as human beings prefer variety in theirs. A closely cropped pasture of nearly pure buffalo grass is entirely too monotonous in appearance and in palatability to be of greatest value in beef production. Overutilization has been found to decrease the number of desirable species in a native range.

Dormant prairie forage is low in succulence and usually low in protein content; hence good rangeland should have at least some green herbage throughout the growing season. The chemical composition of prairie grasses has been found to vary significantly especially in early spring as compared to late fall.

It is well, perhaps, to bring this paper to a close by pointing out the fact that what has been done on the prairies at Hays and elsewhere may serve only as a foundation for greater and more detailed work. These investigations on the vegetation of the mixed prairie and high plains are most refreshing both to the college instructor and to the college students. An opportunity is provided to take the student to the prairie or, when this is impossible, the prairie is taken to the student through exhibits of one type or another. It is hoped by this means to bring together the great out-of-doors on the one hand and the student of nature on the other.

The vegetation of the Great Plains, a vast area of reserve sunshine, of potential beefsteak, of exquisite beauty, has slowly come to us through past ages, and from what we know at the present time these prairies are best preserved through moderate use. The cover of vegetation that is used to build and protect the soil approaches a maximum under moderate use. Also a maximum yield of first-class herbage is thus provided and, finally, there is preserved the beauty in the ever-changing panorama of flowers and color of foliage from one aspect to another as each season progresses.

Nature, indeed, has designed in our prairies a most wonderful soil builder and soil protector. It is necessary, of course, to cultivate the most level portion for the production of wheat and other cereals. When cultivation is practiced, however, it should be done in such a manner that high productivity of the soil may be maintained. There are vast stretches of native prairie that have been put under cultivation during recent years. Some cultivation has been practiced on areas of broken topography where erosion is likely to become serious in a few years.

One of the major problems that is now confronting the farmer of the high plains is how best to reseed to native grass a portion of his land under cultivation. If an adequate supply of grass seed and seed of other plants can be maintained and if techniques of seedbed preparation and reseeding can be improved, it might be possible eventually to grow native grass in a long-time rotation.

It should be the policy of all who live and work in the plains region to learn more of its proper use and, at the same time, how to preserve its beauty. We must have bread made from its wheat but also we should enjoy its beauty—for "man does not live by bread alone."

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FOOD SHORTAGES AND THE SEA ¹

By DANIEL MERRIMAN

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[With 2 plates]

Since World War II our attention has been drawn in forcible manner to the problems created by a rapidly increasing population in a world of food shortages and diminishing natural resources. Such books as Osborn's "Our Plundered Planet" and Vogt's "Road to Survival" paint dramatic and frightening pictures. The press follows with alarmist statements about future depletion or speaks with undue optimism about anything that offers the slightest hope of alleviating critical conditions. Here the oceans come in for a large share of attention, especially with reference to supplying the ever-increasing need for protein. This is wholly natural; the oceans cover nearly three-quarters of the earth's surface, and recent technological advances have led to a number of eminently newsworthy "miracles" of modern fishing, such as electronic aids, "atomic" trawls, electrophysiological fishing, the deep scattering layer, and detection of fishes by the noise they make.

More fundamental than new techniques in fishing, however, is the problem of what food is to be taken from the sea—or, to put it another way, at what point can man most advantageously break into the sea's cycle of life?

This cycle can be said to begin with the vast assemblage of minute floating plants (phytoplankton) and animals (zooplankton) which populate the upper levels of the sea. The microscopic phytoplankton comprising more than 99 percent of all marine plants, creates organic matter from inorganic materials in the presence of sunlight, by the process known as photosynthesis. No animals have this capacity; they must feed either on plants or on other animals that have first fed on plants.

It has often been suggested that the sea's cycle of life might be interrupted right here; and if a way could be found for harvesting phytoplankton and zooplankton for human consumption it might be comparable with the best agricultural practices. But without human

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interference, these minute forms of life are eaten in fantastic quantities by other ocean dwellers. The zooplankton, for the most part, live by eating the phytoplankton. They may then sink to the bottom, where they provide food for shrimps, crabs, worms, mollusks, and smaller invertebrate animals (which in turn may be eaten by larger invertebrates or by bottom-living fishes like flounder and cod), or they may stay in the surface layers—only to be eaten by such fishes as herring, menhaden, sardines, or mackerel, or, paradoxically enough, by the largest of all marine animals, the whalebone or baleen whales. The phytoplankton and zooplankton, the bottom invertebrates, the fishes, the whales—all eventually meet their fate. If they escape predation, they die a natural death and release their inorganic matter for use once again in the continuous cycle of life in the ocean.

Or these plankton, these bottom invertebrates (shrimps, oysters, clams), these fishes (herring or flounder), these whales, may be removed from the sea by man for his use.

The question, then, is this: at what stage in the cycle is it best to take "the harvest of the sea"? G. A. Riley, writing in the October 1949 *Scientific American*, directed attention to this problem in exemplary fashion:

. . . the fishes and other large animals in the sea represent the end product of a long and complicated food chain. Through a series of predations, the tiny bits of plant life are transformed into successively bigger bundles of living material. But all along the way from plants to fishes there is a continual loss of organic matter. During its growth to adulthood an animal eats many times its own weight in food. Most of the organic material it consumes is broken down to supply energy for its activity and life processes in general. It follows that the total plant matter in the sea outweighs the animals that feed upon it, and the herbivores in turn outweigh the carnivores. Fish production is believed to be of the order of only one-tenth of 1 percent of plant production.

To put it another way, we can say that the average annual phytoplankton crop in well-known fishing areas is roughly 500 to 1,000 times as great as the commercial catch of fishes; in short, if an acre of sea bottom yields 50 pounds of fish a year, the phytoplankton production in the overlying waters in that period might be 25–50,000 pounds. At a given time the phytoplankton crop might be only about four times the weight of the fishes, but the microscopic plants grow and multiply so fast that the production in the course of a year is hundreds of times as much as the fish production. And if the annual phytoplankton crop is of this order of magnitude, the zooplankton crop—the next step in the chain—is perhaps 100 times the poundage of the commercial fish catch in the course of a year. Clearly then, by harvesting the fishes, which are at the end of the chain, we are working at the most inefficient level.

Unfortunately, however, nothing can be done about it. There have been devices for the collection of plankton on a limited scale



1. Sorting the catch by species on a small southern New England dragger. The wire baskets hold 1 bushel; the catch is then iced and barreled below decks, 3 bushels to a 200-pound barrel. The day's catch may be from as little as 1 barrel up to 50 barrels, depending on the season and species.



2. The bag or cod end of a small trawl being hauled over the side of a dragger after towing for an hour and a half. Note the variety of species. The strands of rope are to prevent chafing as the cone-shaped net is dragged over the bottom.

(All photographs were taken on Capt. Ellery Thompson's dragger *Eleanor*, out of Stonington, Conn.) (Pictures courtesy H. Gordon Sweet.)



1. Members of the staff of the Bingham Oceanographic Laboratory, Yale University, tagging skates on a commercial dragger. The tags consist of white celluloid numbered disks on which are printed appropriate instructions for their return; each pair is attached to the fish by a nickel pin. This is part of a research program involving the detailed population analysis of the demersal fishes in the Block Island Sound area.



2. Part of the catch in a typical haul from a southern New England dragger. At least eight species are visible. Formerly only those forms that were used for human consumption (in this case, the blackback flounder and whiting) were kept, and the rest shoveled overboard as "trash." Now the "trash" species are frequently utilized in the fish-meal and associated industries.

through the utilization of tidal energy, and by special processing this nutritious material might be made quite acceptable as human food. But the harvesting of a plankton crop would require the continuous filtering of stupendous quantities of water and would demand such an enormous output of energy that any large-scale process of this sort is completely impractical—at least until atomic energy is turned to constructive rather than destructive ends, and even then the problems would be complex. Such harvesting still belongs in the realm of fantasy; to collect the plankton in water of average depth overlying only an acre of fishing bottom would require the filtration of perhaps 50 million gallons of water through the finest sort of bolting cloth many times over in the course of a year. As Riley puts it, "By and large we must leave the plankton to the fishes."

But though we must leave the plankton, are the fishes necessarily the consumers to whom we must leave it? Are there perhaps, other organisms that might be harvested at a more efficient level in the food chain? Oysters, clams, mussels, and other molluscan species feed directly on microscopic plankton; hence there is less loss of organic material than in the end product of a food chain which has involved a number of steps. On this account production is relatively efficient. But as a rule such animals are extremely slow-growing, and since they live in the shallow part of the ocean and are sedentary, they are readily accessible to man; therefore natural populations are likely to be fished out.

For example, Connecticut oyster grounds showed a decline as early as the eighteenth century, and by 1830 the supply had decreased to such an extent that oysters from Chesapeake Bay were imported in large quantities. In the second half of the nineteenth century the highly specialized business of oyster culture developed in Long Island Sound. Then the Chesapeake oyster began to show signs of serious depletion, and by 1900 importation from the South had ceased. As Gordon Sweet points out in the *Geographical Review* (October 1941), oysters were now removed from the low-priced staple food class and the price rose to such an extent that they became a luxury.

Present-day oyster farming in Long Island Sound is a difficult and skilled type of agriculture. Land under water is leased by an act of the Connecticut legislature. The beds must be protected from starfish, which open and feed on oysters by means still not fully understood, and from small snails which riddle the shells with holes, and the oysters must be transplanted to different areas for optimal growth at different stages of their life history. After preparing clean beds of shells on which the baby free-swimming oyster larvae settle and become "spat" during the summer, the oyster farmer transplants his growing crop at least three times in the next 4 years.

Sometime between the fifth and ninth year of life the oyster is ready for human consumption and the edible product is dredged once again and prepared for shipment. Small wonder, under conditions of such a highly developed system of cultivation, that the oyster is a luxury item. Among recent developments in this industry are dredges based on a vacuum-cleaner principle, which can suck up as much as 3,000 bushels in a morning; this mechanism has enormously speeded the transplantation of oysters to different grounds, and obviously it provides for far more efficient control of destructive pests. It is probable that there are still some molluscan sources which are untapped, and there is little doubt that the cultivation of oysters, clams, and other bivalves can be developed on a wider scale. But it is totally unrealistic to look to these sources for any substantial alleviation of world-wide food shortages; the best that might be expected would be limited developments in certain areas which might serve directly or indirectly to relieve critical conditions in minimal fashion.

So we are left with the fact that the great bulk of our harvest of the sea must come from the animals at the end of the food chain—the fishes, which represent the most inefficient level of harvesting. That is to say, they are “inefficient” in terms of total organic production, although admittedly “efficient” in terms of man’s ability to catch fish as compared with his ability to catch plankton.

What, then, can man do to increase the landings of fisheries on a world-wide scale? Are these resources inexhaustible? For example, is the stock of herringlike fishes, which constitutes a major item in the world’s fish production, being depleted to the danger point by the ever more intensive and efficient efforts of man? The world’s annual landings at present amount to perhaps 20 million tons. Can we double those landings in a decade by exploiting the present stocks much more fully? Can we also find new and untapped resources so that the world’s production might be increased many times over—say, ten-, fifty- or a hundred-fold? How much will the expanding science of oceanography and the rapid strides in technology help us to increase the production of our fisheries?

These questions are difficult to answer with any degree of accuracy. Sober thought and judgment are needed lest the misconception that the ocean offers a panacea for food problems become widespread.

Reference has been made earlier to the miraculous aids to modern fishing, some of which can be called electronic. About 20 years ago the conventional sounding lead and line gave way to the fathometer, a machine that measured the time required for sound waves sent out from the ship to reach bottom and return an echo to the ship. Given the speed of sound in water, it was possible to construct the instrument so that the depth of water was recorded on a dial, and measurements could be made continuously under full steam. In the early days of

fathometers on trawlers on the Banks, we would simply turn a switch and a light would flash at short intervals opposite the appropriate depth on a dial reading from zero to a hundred fathoms. With such a mechanism the skipper could drag his net in a gully or depression where he had reason to think there were heavy concentrations of fishes.

The fathometer underwent rapid improvement, and the utilization of supersonic frequencies made it a precision instrument so delicate that it could detect much more than absolute depth. Double "echoes" began to show up on occasion, one clearly from the bottom and the other from intervening layers at mid-depths or less. It became clear that the second reflection, or false bottom, could only arise from concentrations of fishes or other organisms. In the herring fishery of the Pacific coast, schools of varying size occur at mid-depths.

In the old days the fisherman had to depend on a combination of intuition, knowledge, and experience. When a herring seiner arrived in an area where there might be fish, it was common practice to let down a great length of piano wire with a weight attached; a skilled man could tell whether the concentration was light, medium, or heavy by the frequency of pings as the schooling fish hit the wire, and on his say-so was based the decision to set or not to set the net. Nowadays the echo-sounder performs the same function; it, too, can judge the size and concentration of the school by the intensity and depth of the recorded echo. Amazing hauls are made on occasion, as this story from *The Pacific Fisherman* for January 1950 shows:

Something close to an all-time record for a single set of herring off the British Columbia coast was achieved by Nelson Bros. Fisheries' Seiner *Western Ranger*, Nov. 2, with a haul of 1,180 tons of fish. . . . (This) was made possible through the practical application of electronics to fishing. The great school of herring was detected by Capt. Hans Stollen on his vessel's echo-sounder in weather so foggy that no sign of fish could be seen. Acting on information provided by his sounder, he set his net blind and made this enormous catch. . . . *Western Girl*, the flagship of the Nelson Bros. fleet, was close by. . . . The two boats were in constant radio telephone communication with each other while the operation was being completed.

But the echo-sounder alone has not served to bring about a vast increase in the catch of Pacific herring. To be sure, it has replaced a more time-consuming method, it has made fishing more mechanical, and at times it has made possible the detection of herring that might otherwise have escaped the fishermen. But it has not, singlehanded, brought about an increase in the catch of the order of magnitude that here concerns us. The fisherman's accumulated knowledge, his gambling instinct, and other personal factors will not quickly be subordinated to mechanical aids of this sort.

Another discovery resulting from the perfection of echo-sounding devices is the "deep scattering layer," a new term in oceanography.

During and following the war, fathograms in deep water in both the open Pacific and Atlantic have shown the presence of layers, of dubious constitution, that scattered the outgoing signal to varying degrees so that a false bottom appeared at levels down to several hundred fathoms. The nature of this scattering layer has been the subject of inquiry and controversy ever since it was first detected. (See the discussion by R. S. Dietz in the *Journal of Marine Research*, November 1948.) At first it was believed that some physical discontinuity in the water, such as a temperature change, might produce the effect, but the intensity of the scattered sound was often so great as to rule out a temperature change or other physical boundary.

As the records became more abundant, and particularly after they were made continuously over a 24-hour cycle, it became apparent that the depth of the scattering layer differed during day and night. It sank during the daytime and came nearer the surface at night. Such a diurnal cycle immediately suggested that the cause of the scattering layer might be migrating marine organisms. Biologists have long known from laboriously collected net hauls that certain zooplanktonic forms, notably the shrimp and prawnlike types, react negatively to light ("exhibit negative phototropism"). Accordingly, these organisms migrate toward the surface at night, presumably to feed on phytoplankton in upper layers, and then descend to deeper and darker water during the daytime. The extent of these daily vertical migrations is of the order of many hundreds of feet, thus corresponding well with the observed change in depth of the deep scattering layer. Some of these zooplankton are almost microscopic in size, although some, like the euphausiid shrimps, are an inch or more in length. At first it was suggested that the majority of zooplankton were too small to scatter sound effectively; hence, the actual scatterers might be large schools of squid or fishes which follow and feed on the zooplankton, and which the biologist with his clumsy and inefficient nets had not been able to catch. If this were so, the use of sonar gear to detect such schools in the open sea could open vast possibilities for the commercial fisherman.

Unfortunately, the bulk of evidence now favors the view that the scatterers are mainly zooplankton. Recent experiments have shown that minute particles do scatter high-frequency sound, and therefore typical concentrations of even the small-sized zooplankton can account for the deep scattering layer. Certainly more than one kind of animal is involved, and in some areas euphausiid shrimps appear to be the dominant element, but as yet there is no clear indication that squid or fishes are the principal scatterers. At this stage it does not seem that the deep scattering layer is destined to be a tool of great direct significance to the commercial fisheries. Recent calculations have shown that the living populations at depths where the scattering

layer occurs are only about one-tenth as great as those in the surface layers. Furthermore, ordinary echo-sounders are not sufficiently sensitive to distinguish between plankton and fishes, and the oscilloscope, which might reveal the constitution of the layer, could hardly be adapted for use on commercial vessels. All in all, the deeper waters are not likely to contribute greatly to the world's fish landings; fishermen will always get the bulk of their catch from the upper hundred fathoms, the layer in which at least 90 percent of the ocean's living populations exist.

During the war the underwater noises made by marine animals became a matter of great importance to those operating listening devices for the detection of surface vessels, submarines, or other enemy activity. The instruments were developed to a high degree of perfection, but animal noises interfered with accurate interpretation to such an extent that investigations were carried on in the British Isles, America, and also Japan to identify particular sounds with the species that made them. A considerable body of literature on the subject is now available; indeed, certain investigators, instead of sending out the customary scientific reprints, produce actual recordings of their findings; only the other day there came to my desk a record (78 revolutions per minute) of the underwater calls of *Delphinapterus leucas*, the white porpoise—a form of crepitation unrivaled in the annals of phonography.

The underwater soundmakers are of many kinds, such as shrimps, all sorts of fishes, whales, and porpoises. The character of the sound is highly variable, and a recent United States Navy publication on sonic fishes of the Pacific lists the types as follows: Breathing, click, croak, crunch, drum-tap, growl, grunt-groan, hum, rasp-grate-spit, squeak, toot-whistle, and whine-pipe. This same publication states that "subsurface listeners described unidentifiable contacts running the gamut of sound from mild beeping, clicking, creaking, harsh croaking, crackling, whistling, grunting, hammering, moaning and mewling, to the staccato tapping as of a stick rapidly and steadily drawn along a picket fence, of coal rolling down a metal chute, the dragging of heavy chains, fat frying in a pan, simulated propeller noises and the pings of echo ranging." It has been suggested that the identification and association of particular sounds with definite species might be of practical significance to the industry in detecting schools or concentrations of commercial fishes. There appears to be little justification for this optimistic view; it is not likely that the sounds made by fishes will be used by commercial fishermen to any greater advantage in the future than in the past. There is, however, some possibility that certain shrimps, which make a characteristic crackling noise, may be of utility in the commercial sponge industry. These shrimps live in the pores and channels of important sponges, some-

times in great abundance, and there is reason to believe that the shrimp crackle might be a useful tool in establishing the whereabouts and extent of sponge colonies.

New methods of catching fishes, new gear, always excite the imagination and catch the public fancy. Since the war two inventions have attracted particular attention. One, a new Danish floating trawl, has been dubbed the "atomic trawl" because of the reports of its effectiveness. Trawl nets are normally dragged along the sea floor to catch bottom-dwelling species; the problem is to catch those forms that exist in large numbers near the bottom but above the vertical limit of the relatively flat cone-shaped net. The Danes are said to have developed a method of making a trawl work some distance above the bottom and to have made enormous catches thereby. Two boats work some 300 feet apart and the gear is manipulated by a system of floats and balances and by slackening and tightening the towing ropes and wires. Published descriptions are complex and not encouraging to those who might like to experiment. It is probable that the gear is effective in limited areas and under special conditions; the Danes have always excelled in net construction and gear handling. But the "atomic trawl" will not revolutionize the industry, nor will it be a gear which will bring about a great increase in the world's catch of fish.

The other invention, developed in Germany by Dr. Konrad Kreutzer since the war, has been given the spectacular name "electrophysiological fishing." Previous experiments had shown that fishes are responsive to the polarity of electric fields, and when two electrodes are placed in the water, with a varying positive voltage on one, the fishes are forced in that direction. Kreutzer has carried on experiments in Lake Constance and, on a small scale, in salt water; he reports great success and hopes to obtain a patent on the electrode arrangement and on the pulse shape and rate, the pulse form being critical to the success of the whole endeavor. Last summer (1949) he was seeking funds to equip an experimental boat in order to attempt to apply his method to the trawling industry. The anode would be incorporated in the net and the cathode kept near the boat. He has not published quantitative results of his experiments to date and is not willing to reveal all details until he has obtained patents.

However, his accounts are highly enthusiastic and an American Consulate report from Bremerhaven states, "Kreutzer's invention, if successful, will revolutionize commercial fishing." The principle would be applicable not only to the trawl fishery, but to other types of gear, and the inventor believes it would be especially adaptable to the capture of large forms such as sharks, tuna, and whales. Kreutzer himself grants that practical experimentation with electric fishing at sea will unquestionably pose many technical difficulties. For ex-

ample, the fishes will react differently according to their size, and the problem of varying the voltage effectively may prove an obstacle, although Kreutzer discusses this feature only in terms of the conservation of small fishes which are destroyed in normal trawling operations. Also, in his account, the gear, as applied to a special trawl, sounds unwieldy and highly impractical for operation at sea. More fishing gear has been designed on land and failed in practice than any skipper cares to think about. Electrophysiological fishing remains to be demonstrated as a means of increasing the commercial catch, and it must still be regarded with more than a little skepticism.

In short, it is not probable that inventions, new techniques, or modifications of existing gear will immediately bring about such a huge increase in the world's annual landings of fishes as to make notable contribution to the need for protein. The increase in human population appears to be outstripping the ability of science to produce by new inventions the requisite food—at least food from the sea.

The expansion of present fisheries and the development of new ones hold more promise in this regard. For example, the Japanese tuna fisheries in the prewar period were of vast extent; in all probability their precise magnitude will never be known. At present the United States Fish and Wildlife Service has embarked on an extensive study of the biology of the Pacific tunas and a survey of the potentialities of this resource. The area involved is so huge and the problems so complex that results are bound to be slow. However, it is certain that expansion of our tuna fisheries, not alone in the Pacific but elsewhere, will follow in time. Here again the degree of optimism in terms of increasing the world's supply of protein should be restrained. Tuna is costly to produce, and therefore it is not the sort of food that can play a large role in raising the standard of human diet in, let us say, southeast Asia. Other fisheries—notably those devoted to the herring and cod families, will unquestionably expand and develop in new areas.

The biological productivity of the ocean is incredibly high in certain localities, such as the west coasts of Africa and South America; the pattern of current in both places causes upwelling from the bottom resulting in a rich supply of fertilizing nutrients for use by the phytoplankton. Thus the quantities of fish off Peru, where the Humboldt Current exerts its influence, are phenomenal; the cormorants on the three small Chincha Islands (once famous for their guano deposits) have been estimated to consume each year a weight of anchovylike fish equivalent to one-quarter of the entire United States catch of all species. These areas are notably underexploited by man; surely our fisheries will in time exploit them to a much greater degree. How can it be otherwise with Diesel and gasoline engines replacing steam and sail, with a vastly increased cruising radius, radiotele-

phone communication, quick-freezing, radar, and other technological advances? But the extent of exploitation will depend on economic, marketing, and other factors, and it is not likely that these expansions will raise the world's fisheries' production by two or three times within the next decade.

Curiously enough, the development of an ancient practice, fish farming, holds greatest promise for supplying protein in areas where it is most needed and where nutrition is notably below minimal standards. This sort of fish culture, involving the construction of special ponds (either fresh-water or salt) in which all the operations of animal husbandry are practiced, has existed for centuries in China and India, as Hickling relates in *Nature*, for May 15, 1948. The ponds are shallow, roughly 3 to 5 feet in depth, and range in size from less than an acre to 15 acres or more. Frequently they are used for agricultural as well as fish crops—rice, water chestnut, watercress, and arrowhead for human consumption; water lilies and water hyacinth for pig food. These plant and animal crops may alternate—paddy from February to June and fish from July to January—or they may be simultaneous. The ponds are often operated concurrently with vegetable gardens and the raising of pigs and ducks; they are fertilized both naturally and by the application of farmyard manure and compost, resulting in rich growths of plankton and hence tremendous production at the lower levels of the food chain. As Hickling points out, these fish ponds fit in well with a system of peasant small-holding. In some localities the production of fish runs as high as 4,000 pounds per acre annually; contrast that figure with the annual production of 50 pounds per acre from the sea bottom referred to earlier.

The significance of fish farming is by no means as widely understood as it should be. Although the farming of milkfish, carp, mullet, gourami, tilapia, and other species calls for special knowledge, sometimes involving immensely skillful techniques, there is no reason why it should not be practiced more widely and introduced into other areas where it could be developed on a high scale. Production is cheap and yields are high; many areas where human nutrition levels are low are suitable for fish farming (protein shortage is the bane of many tropical populations), and with modern means of transportation the introduction of foreign species is now possible as never before.

Fish farming can be expected to boost the world's production of fish in considerable amounts and to relieve dietary deficiencies in critical areas to no small degree. Expansion of this time-honored practice may yield more than all the atomic nets, electric fishing, electronic aids, and other technological advances put together. This is not to imply that fertilization of large tracts of the ocean by human agencies holds any promise. During the war experiments in Scottish lochs produced greatly increased growth rates in flatfish. Widespread and

unfortunate publicity resulted in the popular misconception that important sea-fishing areas could be similarly treated with comparable results. This is not so; the magnitude of such an undertaking renders it utterly implausible.

Another source of encouragement is to be found in the much fuller utilization of marine products in the last two decades. In some fisheries close to half the fishes caught, many of them killed in the process, were discarded as inedible or nonmarketable during World War II. But we are making rapid advances in this field. New species, heretofore unknown to the housewife, are attractively packaged. Others, until recently unsought, are taken for the vitamin A in their livers. Still others, not readily marketed, are turned to fish meal for domestic animals. Thus there has developed in the past year a "trash" fishery of no small proportions on the North Atlantic coast; nonmarketable species, previously discarded as useless, have been landed in quantity for the purpose. That is why the Bingham Oceanographic Laboratory has paid particular attention to such species as the small skate in southern New England waters. Not marketable directly for human consumption because of its small size and sharp spines (although its larger counterparts are widely eaten, particularly in Europe), the small skate is now being caught in great numbers for use in the fish-meal industry. We need to know how the supply will stand up under intensive fishing, and how its large-scale removal will affect marketable fishes which compete for the same food in the same area. There is reason to believe that catching such skates will benefit other bottom species, such as flounder, which eat the same small animals.

At least 60 percent of the fisheries' products throughout the world are inedible, nonabsorbable, or otherwise unfit for human consumption, but we are learning how to utilize what heretofore has been almost pure waste. These scrap products are useful. Herring scales have recently been worth more to the commercial fisherman than the herring itself—for use in certain "gun-metal" and other paints so common on automobiles. Other byproducts in filleting are used for fish meal or for oil. Some whole fishes are ground up for cat and dog food. No longer do we discard with abandon, and the far more efficient utilization of these resources augurs well for the future.

In the final analysis, however, we must maintain the most cautious optimism about the resources of the sea as a means of alleviating world food shortages. Particular areas and populations can increase their fish production and relieve local protein deficiencies. Our total landings can and will go far above the present catch by using new gear and by exploiting oceanic resources to the full, and we shall learn how to make the most complete use of what we take. But it is unrealistic to think that the ocean is likely to supply a large proportion

of the food required for the world. Let me put it bluntly. Using figures from the United Nations Scientific Conference on the Conservation and Utilization of Resources this past summer (1949), and taking into account the present rate of increase of the human population, if we should double the world's landings of fisheries' products in the present decade—almost beyond the realm of possibility—the ocean would still contribute less than 3 percent to the supply of protein required for the world in 1960.

ECONOMIC USES OF LICHENS¹

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[With 8 plates]

INTRODUCTION

This article is a general discussion of most of the economic uses of lichens. A more detailed account, including the biology of lichens, was published by the present author (13)² in 1944, of which this treatment is a revision of the economic uses only. Neither of these papers is complete but merely an attempt to bring together some of the information regarding utilization of lichens, and a working bibliography for those who have little familiarity with lichenology. None of this material is available in text form; most general texts mention lichens in the most perfunctory manner, citing references only from older texts which give little credit to modern studies.

Though other branches of the botanical sciences have received considerable impetus from the activities of research in recent years, little of this force has carried over into the science of lichenology, which is not a popular study. It is reserved to a few specialists throughout the world whose studies are largely in the realm of lichen taxonomy, geography, and ecology. To the few who have investigated the chemical and physical as well as physiological structure of lichens, all lichenologists owe much for the stimulation they have given to the science. Among these recent contributions attention should be directed especially to that of Quispel (14).

BIOLOGY OF LICHENS

Lichens can be distinguished by their habit of growth as crustose, fruticose, or foliose. The first form is the simplest, growing on bark, wood, rocks, or soil; the other two forms are more intricate, either erect and branched or flat and leaflike, generally with a dorsal and ventral surface, although some forms are pendent and cylindrical.

¹ Reprinted by permission from *Economic Botany*, vol. 2, No. 1, January-March 1948, with revisions by the author. Dr. Llano is now research and editorial specialist, Arctic, Desert, Tropic Information Center, Library Division, Headquarters Air University, United States Air Force, Maxwell Air Force Base Alabama.

² Numbers in parentheses refer to literature cited, at end of article.

These plants are widely distributed from the Arctic to the Tropics, consisting of thousands of species and innumerable varieties and forms. They have one feature in common that distinguishes them from all other plants. Each of them consists of two different and separate entities living together in such a balanced relationship that they not only form a successful organism but are able to reproduce the unit. One component is a fungus, usually an ascomycete but in a few cases a basidiomycete, whose intertwining, compact hyphae give form to the thallus. The other component consists of a species of green or blue-green algae enmeshed between the hyphal strands of the fungus. In this combination, each component is able to extend its activities into habitats that would be inimical to it as an independent organism. Together they form a particular species of lichen with specific morphologic, taxonomic, ecologic, and sometimes physiologic characteristics, the fungal part growing by extension of its hyphae, the algal cells by division.

This intimate relation of fungus and algae is a physiological union usually regarded as one of symbiosis, i. e., of mutual benefit to each component, the fungal element deriving food from the green alga, and the alga benefiting by having its moisture and mineral nutrition maintained through the water absorption and water retention characteristics of the fungus. The presence of fungal haustoria, however, and the penetration of hyphae into the algae have been cited as evidence that this relationship is merely another case of parasitism. Furthermore, the algae are commonly found freely growing in nature; lichenized fungi are not known to survive independently.

As a taxonomic group lichens are open to fair and persistent criticism. The International Rules of Botanical Nomenclature (art. 64) definitely rejects any taxonomic group derived "from two or more discordant elements." This should legally dissolve the biological union traditionally accepted as the class Lichenes. The dominant element of the union is the fungus, and through it the union is able to perpetuate the unit; the sexual reproductive elements are fungal, resulting in the development of typical apothecia or perithecia in which are developed spores. In the process of thinking about and describing the unit, the fungal characteristics are usually uppermost. The inevitable result has been that many mycologists have segregated the various groups among those fungi that appear to have a close relationship.

However, the thallus is a specialized type of structure, and the fungus-alga relationship makes possible specialized functional relationships peculiar only to lichens. They may be conveniently treated as a homogeneous group, for they have their own literature and specialists who concentrate their studies on them.

The fungal components of lichens reproduce sexually by means of ascospores, or basidiospores, depending on the type of fungus-symbiont present. When these spores germinate, however, growth cannot continue unless the resulting hyphae come in contact with the algal associate in the lichen species. A commoner method of propagation, and perhaps the more successful, is asexual. This may be merely by broken pieces of the thallus body being blown or carried elsewhere, or by detachment of a minute mass of hyphae enclosing algal cells from specialized structures known as soredia; this secondary method of reproduction is not found in all species of lichens. Lichens have been synthesized in a few cases by bringing together the two component parts.

Lichens are often mistaken for mosses, but the term "mosses" is popularly used to include many unrelated plants. Certain species of the lichen genus *Cladonia* are known as reindeer moss notwithstanding the fact that they lack stem and leaves so characteristic of true mosses. Irish moss is an alga (*Chondrus crispus*) of shallow coastal waters. The Spanish moss of the interior wooded valleys of California is a lichen, *Ramalina reticulata*. The same name is more commonly associated in the southern States with an epiphytic plant growing on trees, wires, and roofs of houses. It possesses leaves, stem, true roots, and flowers. This flowering plant (*Tillandsia usneoides*) is a member of the pineapple family. Characters of a very general nature might be used to differentiate the various groups:

- A. Plants reproducing by flowers and seeds..... PHANEROGAMS
(Seed-bearing plants)
- AA. Plants lacking flowers and seeds, reproducing by spores.... CRYPTOGAMS
(Non-seed-bearing plants)
- B. Plants with stem and leaves..... TRUE MOSSES
- BB. Plants without stem and leaves.
 - C. Plants normally found immersed in water, commonly bright green, brown, red, or yellow-green, either attached or free floating..... AQUATIC ALGAE
 - CC. Plants normally not immersed in water, gray or bright colored but rarely bright green unless moistened, found on soil, rocks, wood, or bark..... LICHENES

LICHENS AS FOOD FOR INVERTEBRATES

Certain studies (19) concerning invertebrates known to feed partly or wholly on lichens include the feeding habits of mites, caterpillars, earwigs, black termites, snails, and slugs. Invertebrates apparently feed on all but the most gelatinous lichens which have almost complete immunity because of their slimy covering. Dry, hard lichens are rarely attacked, although it has been noted that two species of snail graze on the endolithic lichens *Verrucaria* and *Protoblastenia*, mainly on the thalli and the apothecia. Excrement from these snails con-

tained fragments of calcium carbonate and green algal cells, while the hyphae and dead algal cells were apparently digested. Experiments have shown that snails will feed on potatoes covered with cetraric, rhizocarpic, and pinastrinic acids, poisonous to other animals, but will not feed on vulpinic acid, which is recognized as poisonous to vertebrates. Bitter-tasting lichens, treated by a soda method to extract the acids, were acceptable in preference to fresh untreated but moistened lichens. This is of interest, since there is a widely current assumption that lichens are remarkably well protected against attacks from animals by reason of these acids.

Free-living algae are the preferred foods of invertebrates, in most cases, but when not obtainable, the gonidia, i. e., the algal layers in the lichen thallus, are taken. Some lichens are normally scarred from snail feeding; *Umbilicaria mammulata*, common to the eastern United States, is frequently seen with the dorsal surface marred. Hué (13)³ presented the opinion that the abundance of lichens in Arctic regions results from the comparative absence there of snails and insects. Not a few "new" species of lichens have been the result of insect and snail ravages, further modified by plant regeneration.

LICHENS USED AS FODDER

Nongrassy ranges.—This subtitle refers specifically to range lands which are composed primarily of lichens or which are used at definite times of the year for grazing because of the lichen vegetation. Such areas are rarely entirely free of sedges, grasses, herbaceous plants, low bushes, and sphagnum bogs. When this type of vegetation is at its best in spring and summer, it has little value as nongrassy range land. These areas lie north of the tree line and above timber line but may extend well down into the timber along mountainsides. They are best developed in sub-Arctic regions but may extend into the temperate zones. They cover those parts of Greenland which are ice-free and still have sufficient moisture for plant growth, Iceland, northern Scandinavia, Siberia, Alaska, the Northwest Territories of Canada, Labrador, and the archipelago of the Arctic Sea. As a whole, the thousands of square miles composing this area furnish nongrassy range feed in the winter for wood buffalo, musk ox, caribou, and other wild herbivores, and for domesticated reindeer, as well as a grassy range feed at all other times. It is not to be assumed from this statement that all these wild species of animals are entirely dependent on lichen forage for winter grazing. Actually, too little is known of their food preferences to permit a definite statement.

In the Antarctic regions, though lichens are the predominant plants, they are not so richly developed as in the Arctic. Owing to absence

³ Citations not recorded in the bibliography of this article may be found in the author's 1944 paper (13)

of herbivores in this area, further discussion of it will be omitted. The extreme southern part of South America, Tierra del Fuego, and lower Patagonia might also be included in this classification. Santesson of Uppsala, Sweden, has related to the author that when he was botanizing in the Argentine during the late war, he was approached by government officials requesting advice on the practicability of importing reindeer into those regions for the use of the natives. Santesson's opinion, based on his thorough knowledge of lichen species and of reindeer culture, indicated that the South American lichen species of the area under consideration, although probably acceptable to reindeer, were not abundant enough to sustain them. A news report of October 20, 1947, however, stated that 20 reindeer had been imported into Argentina for stocking the Tierra del Fuego area. These were to provide food, clothing, and transportation to the 3,513 inhabitants of the archipelago, and were part of the Plan Quiquenal "which will make Tierro del Fuego a magnificent exponent of social and economic progress . . ."

In the development of the reindeer industry in Alaska, Eskimos were used as herdsmen, and proved skillful in handling the herds. But stiff competition from other branches of commercial animal husbandry and the inimical attitude of allied companies restricted the normal outlets for reindeer products. Finally the United States Government, and later the Canadian Government, were called upon to assist the Eskimos in developing their own herds, as a means of establishing a more stable source of food and clothing. This venture proved less successful than anticipated, owing largely to the unwillingness of the settled villagers to take up the nomadic life demanded by reindeer herding. With the communal herds restricted to the proximity of the villages, overgrazing, especially of winter lichen pastures, resulted. The seriousness of this problem was brought out in a report of the United States Department of Agriculture as early as 1929, when the reindeer herds were on the decrease.

The American caribou and the Old World reindeer have similar habits, feeding on lichens in snow-free areas or pawing away the snow cover to obtain better grazing. In summer they migrate to the highlands or close to the coast, partly to avoid insect pests and partly to feed in fresh pastures. The constant, natural rotation of caribou during the winter period throughout their range, and migration during the spring and summer from the lowlands to the highlands, prevent overgrazing in any one part of the available range. In Lapland, where reindeer culture has developed through centuries, following the migration of herds from lowlands to highlands, with continual movement throughout the critical winter period, is a natural part of the existence of the herd owners. The increase of northern European reindeer populations has resulted in the development of local restric-

tions and international laws for the control of herds crossing the Norwegian, Swedish, and Finnish boundaries. It has also encouraged the study of the utilization of northern pastures, the vegetational cover, and the study of lichens which are primarily winter feed but are taken at all times of the year by reindeer.

Lapp culture is primarily a reindeer culture, so specialized in its application that the Lapps have derived their own Lapponian terms for varying types of reindeer grazing lands and lichen species which they differentiate sharply, no mean feat in itself. The living problems of present-day Lapps arise mainly from the fact that some of them have given up their nomadic habits and hence their main source of revenue, reindeer herds. The Norwegian, Swedish, and Finnish Governments are conscious of their responsibilities toward these people and of the importance of helping them maintain their culture, and so they encourage lichenologists to make studies and surveys of the lichen flora in those countries.

Reindeer have a market value of from 200 to 300 Swedish kroner (3.60 Sw. kr.=\$1, August 1947), and it is not unusual for a Lapp to possess several thousand animals; such a person can hardly be considered indigent. Reindeer meat is unrationed and is served throughout Fennoscandia. The hide is used for leather goods and, with the hair, is manufactured into footwear and a high-quality sleeping bag. During the war German troops stationed in Finmarken slaughtered reindeer indiscriminately for meat and hides.

Reindeer culture is not peculiar to the Lapps but prevails also among other nomadic tribes inhabiting lands bordering the Arctic Sea from Murmansk across and down into Siberia. This is partly indicated in a study (8) on the chemistry of under-snow fodder for winter pastures of reindeer in the U. S. S. R. The United States Government and the Canadian Government have embarked upon a program of wholesale importation of reindeer into northern areas without consulting or encouraging lichenological studies or surveys as a basis for selecting nongrassy range lands for the highest relative pasture capacity.

With an increase of both native and white populations in the Arctic and sub-Arctic areas, the demands upon food, particularly meat, are increased beyond the normal available supply of wild game. This necessitates a more realistic evaluation of the proper and normal utilization of uncultivated plants of the northern submarginal pastures. Agriculture, for many reasons, is limited, even for the raising of fodder; the expense of maintaining and caring for domestic herds of animals under rigorous summer and winter conditions is apparent. The availability of large, self-sustaining herds, inured to Arctic weather, requiring a minimum of care, but providing not only the essentials of food and clothing but transportation if needed, would

contribute stability to an economy sustained by an expensive, tenuous, supply line that is easily upset by the contingencies of military priorities.

The most useful species for grazing are the so-called reindeer lichens, *Cladonia rangiferina* Web., *Cl. alpestris* Rabenh., and *Cl. sylvatica* Hoffm., though the last is sometimes said to be refused by reindeer. Probably others, e. g., species of *Cetraria*, *Stereocaulon*, and *Alectoria*, are accidentally or preferably taken, since they are found growing with the former. The Cladoniaceae are the most important, for they grow in carpetlike masses to a height of 6 inches. Their dependence on the substratum is not clearly recognized, since they grow almost equally well on all available areas, especially after fire, competing with and preventing the development of certain seedlings. They may be covered for long periods by snow, but the animals that are accustomed to feed on them are capable of finding them under snow cover. The use of lichens as accessory fodder has always received attention in northern Europe in times of forage (wild or cultivated hay, grain, etc.) scarcity, and in some regions the plants are regularly used for this purpose.

Lynge (13) presents his own and other investigations concerning the food value, harvesting methods, and growing habits of lichens in relation to the feeding habits of reindeer and cattle. He states that in 1916 the large lichen fields of Finmarken maintained 100,000 head of reindeer, resulting in a serious overgrazing problem. Smaller fields in other Norwegian provinces supported 50,000 of these animals. To remedy these conditions, regulations prohibiting reindeer pasturing were put into effect where necessary until good growth was reestablished. Under conditions of unrestricted grazing, lichen vegetation may be seriously altered, while mere trampling by large herds in small areas will destroy these plants. Under such a situation fields of *Cl. alpestris* may be invaded by less desirable *Stereocaulon paschale* Fr., which produces full-grown thalli in 5 to 6 years after which *Cl. alpestris* again becomes dominant.

In Lynge's account there is a list of Lapponian lichen terms indicative of some of the peculiarities connected with reindeer husbandry. The Lapps differentiate between lichens and mosses, since reindeer never feed on the latter. "Jaegel" refers to field lichens on which reindeer fatten; "Gadna" occurs on stones and trees and are eaten if no other food is available; "Lappo" are the beard forms growing on trees for which the animals have great fondness. The Swedish Government permits the Lapps to cut down birches in winter emergencies to enable the reindeer to get at this type of feed. The herders also recognize the pasture cycle after fire with its successive lichen formations. Reindeer feed on the younger parts or tips of the plants.

The relative abundance of these economic lichens would be best stated as "generally common," for solid areas of any one species is the exception rather than the rule. *Cetraria islandica* Ach. in average areas yields about 700 kilo of air-dried "moss" per square kilometer. *Cl. alpestris* gives higher yields, and selected areas in northern Norway have produced 1,400 to 1,500 kilo per 1,000 square meters.

Harvesting is performed by hand or hand implements; this is for the use of domestic animals only, for even the Lapps keep goats or a cow in addition to their reindeer. Among the Lapps the work is performed by the women and by hand, a method considered conserving and cheap, since only a quarter of the quantity growing is thus garnered, leaving enough for regeneration. The Norwegian method, using rakes with 15-centimeter teeth, takes up to two-thirds of the amount available. Sticks are shaken out, and the adhering soil may be separated by water. Dry "moss" is brittle and to avoid large losses is most economically harvested when having a water content of 40 to 70 percent by weight. As the plant is gathered it is piled into small heaps (40 to 50 centimeters high) with a branch of birch in the center for a handle. These small heaps are brought together to form large bundles. They are moved around in the field on sunny days when the water content may go down from 60 to 30 percent, and are then placed in straw-covered shelters. In winter they are taken to a drying house in sledge loads of from 300 to 600 kilos. The crop may be further dried in a warm ventilated room and stored when the water content has gone down to 14 percent of the dried weight. Hand presses are unpopular because of their cost and weight. Transportation costs for this type of forage is considered expensive, and the forage is never transported far.

One cause for occasional friction between the Lapps and the Scandinavians in these northern areas is the more thorough harvesting methods of the latter which have caused the Lapps to complain of loss of grazing areas. Reindeer crop the lichen close but leave enough of the thallus for future growth and the possibility that the area can be pastured again within 4 years. Hand harvesting or implement harvesting uproots the lichen thallus, and it may take ten or more years for regeneration and growth. This situation has been alleviated by regulations imposed by the local governments. Lichens on trees may be scraped away and gathered in sacks by non-Lapps.

A farmer having 10 cows and some sheep and goats uses yearly 60 sledge loads of lichens for his stock. This implies a need of 4,800 to 18,000 square meters of well-covered lichen fields per year. Since these plants may require up to 30 years to regenerate a marketable stand, a farmer must have access to 150,000 to 560,000 square meters of land. This land must be preferably mountain or heath land, since forest areas contain objectionable pine needles and sticks. However,

few farmers give so much lichen fodder to their cattle, actual amounts depending on the quantity of grass available. In "moss" districts three to five sledge loads are collected per cow. It is possible for one man to gather from 50 to 100 kilos by hand per day or with implements to increase this up to 300 to 400 kilos per day. Even in older times it was difficult to get laborers for gathering lichen fodder, owing to the small pay, and it was necessary for the State to intervene. School classes were encouraged to collect, receiving 3 ore per kilo per student and 1 ore per kilo for the teacher (4).

As an additional food for domestic animals, especially swine, lichens are of value, and Lynge recommends greater use of *svinamöse* (swine-moss) for these animals. Jacobj (13) found that young pigs thrived better on a combination of reindeer moss and ordinary feed than with the latter alone. He also satisfactorily fed rabbits and hares with *Evernia prunastri* Ach. after extracting the acids. Icelanders feed *Cetraria islandica* to their cattle, pigs, and ponies. It has also been reported good for oxen, while the richness of the milk of the small cows of northern Scandinavia is attributed to this food. An early traveler relates that during a period of famine in Finmarken, the farmers preferred to feed *Cetraria islandica* to their cattle than to use the lichen themselves for food and risk the loss of their cattle. Cows were given 10 kilos, horses 6 to 8 kilos, swine 2 to 3 kilos, and sheep and goats 1 to 2 kilos daily (4).

Nutritional studies.—The nutritive value of these nongrassy range feeds apparently lies in their high lichenin (lichen starch) content. Hesse (13) worked out a comparison of the sugar content of lichens with that of potatoes and found that for *Cetraria islandica* the proportion was 1 of potatoes to 3.35 of lichen; for *Cl. rangiferina*, 1:2.5. The former has been found to yield 61 percent carbohydrates and other products of its hemicelluloses. The bitter principle, due to the presence of lichen acids in even the mildest of these plants, can be removed in order to make the fodder more palatable to domestic animals. This is done by soaking them in water for 24 hours or by addition of potassium carbonate to the water for quicker action. Boiling with lye, after which the lichens are thoroughly rinsed with water, is the usual method of preparing the plant for human or animal consumption. Sometimes the lichens are mixed with hot water and straw or meal, and salted before being fed to cattle; the proportion of meal and salt is gradually reduced until the cattle become accustomed to the lichen alone. One kilo of *Cl. rangiferina* (15 to 18 percent water content) is considered to be equal to one-third poor fodder or early grass. By analysis this lichen is found to contain 1 to 5 percent proteins, the rest carbohydrates and little or no albumen (4).

Russian investigations of the under-snow fodder from winter pastures at the Saranpaul State Reindeer Farm indicate that winter herbage is rich in crude fats and in nitrogen-free extracts, and that the content of fiber and hemicellulose is higher in winter than in summer herbage. Chemical study of winter and summer lichen herbage showed a higher protein than fat content, particularly in *Alectoria jubatta* Ach. (7.77 percent) and *Umbilicaria pensylvanica* (6.27 percent) which varied with the season (4).

Use of lichen fodder in Europe goes back into antiquity, as indicated by prehistoric remains found near Lake Constance in Switzerland (19).

LICHENS USED AS FOOD BY MAN

History.—From the earliest times the food of man has included lichens, sometimes as a delicacy, but more often as a last resort in the face of starvation. Their commercial importance as food for man, however, has decreased, though Hanstien, chief lecturer in the Agricultural School at Aas, Norway, long ago prophesied that lichens are destined to become the great popular food for the masses because of their cheapness and nutritive value. The use of lichens for human food has been revived at times, and they were recommended in Sweden as substitute food in 1826, 1841, and 1868 after bad frosts and droughts had affected regular crops. In general, the bitter principle in these plants gives them an unpleasant flavor and unless removed exerts an irritating effect upon the digestive tract of man, causing inflammation.

Cetraria islandica probably rates first as lichen food for humans. It is gathered commercially in the Scandinavian countries and in Iceland and sold on the market as "Iceland moss." Schneider says of this "moss": "Inhabitants of Iceland, Norway and Sweden mix this with various cereals and mashed potatoes from which an uncommonly healthful bread was prepared." Lynge (13) quotes a tradition "that there was no starvation at Modun in 1812 as long as there was brodmöse (bread-moss) left in the forest." Icelanders made the most of lichens as food for humans, collecting great masses of this plant yearly. Two barrels of clean lichens pressed down gave the equivalent of one barrel of the usual grain meal. From this flour they made bread, gruel, porridge, salads, and jelly in various ways. Milk was added and in this form the lichen was the basis of various light and easily digested soups and other delicacies said to be of value for dyspeptics. It was also mixed with flour in making a nonfriable ship's bread which was less subject to weevil attack than ordinary bread. In northern Finland, in times of famine, reindeer moss and rye grain were made into a bread having a taste like that of wheat bran but leaving a sense of heat on the tongue.

Before use the lichen was boiled with lye, rinsed in clear water, dried and placed in closed containers which were stored in a dry place. In this fashion it would keep for many years. For breadmaking it was first oven-dried, then ground fine; one-fourth grain meal was next added, and the mixture was baked as usual, producing a strong bread with a fair taste which kept well in storage. *Cetraria islandica* was also mixed with elm cortex as well as with grain and boiled with a surplus of water to produce a broth. *Cetraria nivalis* was occasionally used in the same manner. For porridge, a cooking container was filled with one-third *C. islandica* and water, and this mixture boiled three or four times and stirred frequently until it became thick. The top broth and scum were skimmed off and the rest salted according to taste. This was permitted to cool until hard, then eaten with or without milk. It could be redried in an oven and used for bread. As gruel, about 1 pound of the finely cut lichen was added to $1\frac{1}{2}$ to 2 quarts of water and cooked slowly until about one-half of the water had been evaporated. This was strained while hot and flavored with raisins or cinnamon. After boiling, and separating the broth, the residue was eaten with oil, yellow of egg, sugar, etc., as a salad, "and the most pretentious person will like it." The hardened jelly of this lichen was often mixed with lemon juice, sugar, chocolate, almonds, etc. (4).

The Biblical manna of the Israelites appears to have been *Lecanora esculenta* Evers. (19), which is still eaten by desert tribes, being mixed with meal to one-third of its weight. This lichen grows in the mountainous regions and is blown loose into the lowlands where the thalli pile up in small hummocks in the valley. As late as 1891 there was an abundant fall of this "manna" in Turkey. The Turks are recorded as using *Evernia prunastri* for jelly (4); the ancient Egyptians also used this lichen and *E. furfuracea* in making bread (13). There is still some importation of these lichens from Europe as fermentative agents, and Forstal in the nineteenth century reported seeing several consignments from the islands of the Greek archipelago bound for Alexandria. In India (17) *Parmelia abessinica*, "Rathipuvvu," is used as food, generally in a curry powder, and medicinally; while in Japan *Umbilicaria esculenta* is considered a delicacy and sold as "iwa-take" or "rock mushroom." Because of the scarcity of collecting places and the difficulty of access, the market price is relatively high. In France lichens are used in the manufacture of chocolates and some pastries; the lichenin is, in this case, merely used as a filler and a substitute for commercial starch.

Less is known of the uses of lichens by northern Asiatic peoples. Their dependence upon reindeer husbandry reaches far back into antiquity; lack of open coastal Arctic waters rich in sea mammals, the vastness of the interior Asiatic land mass, and the cumulative, migratory populations have forced a situation upon a normal nomadic hunt-

ing society that has resulted in the symbiotic relationship of man to reindeer more or less throughout an area south to latitude 50° N. The relatively smaller aboriginal populations of Arctic America have found the rich coastal waters capable of supporting their hunting, nomadic existence so satisfactory that even during recent times reindeer husbandry has had little appeal for them. The American Eskimo lacks any tradition, according to present information, in the use of lichens even as a starvation food. Present-day natives have been observed collecting *Cetraria richardsonii* as tinder to fire wood in five gallon cans. Wicks of the primitive stone seal-oil lamps were either *Sphagnum* or *Eriophorum* tufts. In the hunting of the hoary marmot, a commercially desirable fur mammal, the Eskimo hunter locates entrances to burrows along scree and talus slopes by seeking patches of bright-yellow *Xanthoria* species. This lichen responds readily to the presence of nitrogenous substances, and displays a more vigorous growth in those spots where the marmot habitually evacuates close to its burrow.

The American Indian's knowledge of wild food plants included the use of *Alectoria jubata*, though there are indications that some of the more primitive Pacific coast tribes made greater use of these plants. "Tripe de roche" or "rock tripe" was so named by the French "coureur de bois" of boreal America who used it in periods of emergency. Franklin recorded it in his diary as the main course of many a meal. This "rock tripe" is one of the Umbilicariae and must be treated with boiling water or at least soaked before being eaten. Franklin's use of this lichen has been quoted many times, though the complete report states that the species used caused severe illness. This was probably the basis for the recommendation to personnel of the United States Army Air Forces during the war for its use under emergency conditions in Arctic areas. It may be noted that members of the Franklin Expedition were also boiling and eating the leather of their equipment. Under such starvation conditions any type of food or plant may be used in an attempt to allay hunger. But under a preplanned program designed to educate personnel with a minimum of out-of-door experience and no knowledge of plants suitable in such eventualities, a greater emphasis on the more common vascular plants and of the animals in these regions would have been more applicable toward the preservation of life. Lichens are not easily recognized, and their preparation with fire presumes the accessibility of fuel which may not always be available. Future recommendations must be based on more thorough research studies.

Nutritional studies.—Scientific investigations regarding the digestibility of lichens and the behavior of lichen substances in the body have been too few, but the evidence at hand does not agree entirely with the fact that these plants have been used extensively as foodstuffs.

Analyses have shown that they contain a variety of carbohydrates of which polysaccharides are the most common, giving rise on hydration to several sugars, some cellulose, chitosan, glucosamine, and inulin. Of these the only compounds directly available in intermediate metabolism are the simple monosaccharides, i. e., six-carbon sugars. Polysaccharides apparently need to be split into "physiological" sugars before they become available to the body. Uhlanders and Tollens (13) noted a difference in the occurrence of characteristic carbohydrates in various lichens examined, though they all contained some lichenin. Thinking that the substances in *Cetraria islandica* and *C. nivalis* were similar, Poulsson (13) made a bread from these two species to determine their use in diabetes mellitus. Though 46 to 49 percent of the carbohydrates of the former species was digested, the latter species caused such intestinal disturbances that the experiment had to be discontinued.

From a correspondent the author has received interesting information on the personal use of *Cladonia rangiferina* to combat anemia and a general run-down condition. The individual attempted self-medication with this lichen on the advice of a Norwegian professor who recommended the treatment as an old-time remedy. He reported a gain of 7 pounds in 1 week and return of normal skin color and physical strength, and states that he has become extremely active. It is not known how the lichen was prepared, but the original supply was obtained from Norway notwithstanding the fact that it is a common plant of North America.

Brown (13) failed to induce glycogen formation in rabbits by feeding them lichenin obtained from *C. islandica*. Ordinarily neither hydrochloric acid (0.3 to 0.5 percent) nor amylolytic enzymes have any noticeable effect on lichenin, while iso-lichenin is, at most, converted into a dextrinlike form without producing sugar; the action of bacteria yields acetic, propionic, butyric, and lactic acids.

More recently Wallerstein (13) fed mice white bread, later replacing it with lichenin, and showed the latter to be 53 to 64 percent utilized. Similarly Shimizer (13), in determining the influence of some polysaccharides on the protein balance of a dog, found that they were digestible and available foodstuffs in the alimentary canal. Later he digested polysaccharides in vitro, using extracts of macerated intestine and pancreas in an 0.8-percent NaCl solution, but found no monosaccharides. He took this as evidence that there are no enzymes in the digestive system of mammals capable of splitting inulin, lichenin, or hemicelluloses. On determining the action of fecal material and fermentative bacteria on these substances, Shimizer and Tonihide (13) concluded that they are split into sugars by the bacteria in the digestive tract of mammals and can then be absorbed.

It has been assumed in the past that the presence of the enzyme lichenase in the stomach contents of the ox and pig probably enables these animals to convert lichenin into the more digestible sugars. The action of snail lichenase on lichenin in vitro has been found to produce cellubiose and lichosan, an anhydride of glucose similar to cello-san, a product of cellulose. Messerle (13) states that the livers of snails contain much lichenase, which converts cellulose to sugar. Jewell and Lewis (13) had found this to be true of many invertebrates, suggesting that the ability to hydrolyze lichenin may be characteristic of invertebrates only.

Swartz (13) questions the value of algae and lichens as sources of energy in nutrition. Oshima suggests that they may be valuable for their inorganic salts, while Prausnitz (13) calls them "faeces-forming foods" in that they stimulate intestinal activities. Most of Swartz's studies were on the algal components, yet she was able to draw certain conclusions concerning those chemical substances which are common to both components. They were:

a. Nutritive studies of lichens would indicate that as energy-producers their value is not appreciable. Yet the fact remains that certain animals do feed upon them and thus sustain themselves in regions where energy and high body heat are prerequisites of life. The assumption follows that our understanding of the value of lichens as fodder is still incomplete, though ruminants are apparently more effective users of hemicellulose than other animals.

b. Aerobic and anaerobic bacteria, not enzymes, are responsible for conversion of hemicelluloses into sugars. The amount available to the animal system is extremely diverse, depending on the animal and the lichen species.

Vitamin studies.—Blix and Rydin (13) found that *Cladonia rangiferina* contains some ergosterol, more than most lichens, but the content is low in comparison to that in yeasts and molds. This same species collected in Uppsala in August and September showed only traces of vitamin D. Bustinza and Lopez report (3a) that they "obtained a fraction very rich in ergosterol" from *Evernia furfuracea* collected in Spain.

Experiments with rats in Alaska, using lichens arbitrarily divided into short- and tall-growth forms, indicated that the animals would not tolerate the latter group (Cetrariae, Cladoniae) at levels greater than 10 percent in pure diets. Short-growth types (Alectoriae, Stereocaula, etc.) appeared more palatable. Vitamin-A and -D response was obtained from tall-growth types; vitamin-B complex was absent in both groups. Bourne and Allen (13), using acetic acid-silver nitrate reagent for vitamin-C, obtained a positive test.

MEDICINES AND POISONS DERIVED FROM LICHENS

The name "lichen" (=leprous), originally applied to hepatics, is of Greek origin and was used by Theophrastus in his "History of Plants" to describe a superficial growth on the bark of olive trees. Dioscorides applied it to true lichens because of their resemblance to the cutaneous disease for which they were supposed to be specific. This is substantiated by Andres de Laguna (9a). Dr. Bustinza brought this to the attention of the author, remarking further that the illustration of *Lobaria pulmonaria* (9a, 1566, p. 407) may be the first drawing of a true lichen.

History.—The use of lichens in medicine can be traced back to antiquity. *Evernia furfuracea* has been found in an Egyptian vase from the eighteenth dynasty (1700–1600 B. C.), and is still imported into Egypt from Europe and sold with *Cetraria islandica* as a foreign drug. The Egyptians also used this species of *Evernia* to preserve the odor of spices employed in embalming mummies (13a). Edward Tuckerman (20a) reports a similar or perhaps the same incident, noting that the specimen examined by him resembled local material. The lichen was sold on the Cairo drug market under the name of "kheba."

In the fifteenth century A.D. there was throughout Europe a constant attempt to follow the guidance of nature in the study and treatment of disease. It was believed that Providence had scattered here and there on plants "signatures" of more or less vague resemblances to parts of the human body, or to diseases to which man is subject, thus indicating the appropriate specific. This era climaxed the commercial importance of these plants, for never before or since have they played such a unique role in the world of economic plants. The long filaments of *Usnea barbata* Web. were used to strengthen the hair, though Hippocrates also prescribed this lichen for uterine ailments. The natives of the Malay Peninsula still use a closely related species for treating colds and strengthening after confinement (13). *Lobaria pulmonaria* Hoff. was the suitable remedy for lung troubles. Boerhaave (19) regarded it as an excitant, tonic, and astringent, and recommended it for hemorrhages and asthma. *Xanthoria parietina* Th. Fr., being a yellow lichen, was supposed to cure jaundice, while *Peltigera aphthosa* Willd., the thallus of which is dotted with small wartlike tubercles, was recommended for children who suffered from thrush. Other species of *Evernia*, *Peltigera*, *Parmelia*, *Cladonia*, *Roccella*, and *Pertusaria* were used as purgatives or to control fevers, diarrhea, infections, skin diseases, epilepsy, and convulsions. *Pertusaria communis* DC. was used to cure intermittent fever, having less action on women than on men. *Peltigera canina* Willd., as a cure for hydrophobia, was sold by a Dr. Mead as the celebrated "Pulvus antilyssus" (Dillenius,

1741). The so-called drug "Lichen quercinus virides" consisted mostly of *Evernia prunastri*, *E. furfuracea*, and *Parmelia physodes* Ach., (19). The doctrine reached the height of absurdity in the extravagant value set on a lichen found growing on human skulls, "Mucus cranii humani." This skull lichen (*Parmelia* or *Physcia*?) fetched its weight in gold as a cure for epilepsy.

Luyken, in his "Historia Lichenum in Genere," Göttingen, 1809, gives a long list of medicinal "Lichenes, quorum usus obsoletus est." Plitt (13) recommended more emphasis on the study of lichenology to pharmacognosists, venturing the opinion that the medical virtues of bark drugs may be affected by the lichens growing on them. Feé dealt earlier on this subject in a beautifully illustrated treatise (7).

Iceland Moss was recognized by Linnaeus as a medicinally valuable plant. It was used in chronic affections as an emollient and tonic, and it would indeed have been a "Divine gift to man" had it lived up to all its prescriptions. With the exception of this lichen, all have been replaced by more effective modern drugs so far as medicinal use is concerned. Tavares (in correspondence) reports that the soredia of *Usnea* species is applied as a medicine today in country districts of Portugal.

The use of lichen "leaves" as an insecticide, narcotic, and in magic concoctions under the name of "natema" by the Jivaro Indians has been reported by various travelers. It has now been verified that the "leaves" in question are those of several well-known phanerogams long used for these properties. There are no authentic reports in the literature of lichens being utilized by natives of South America. Among the collections of the late Dr. O. F. Cook were found two packets of lichens purchased by him in the Indian market of Sicnani, Peru. One was annotated: "Intisuncja, mealy beard of the sun, grows on the ground in high summits near the glaciers; taken as tea for coughs, etc." The other was "from the same places" but named "Pachacuti, a medicine for fever." Both were Roccellaceae.

Physiology.—The physiological action of the cetraric acid of Iceland moss has been studied by Kobert (13). It has no poisonous effect either when injected into the blood or when taken into the stomach of small animals. Small doses induce peristaltic movements in the intestines. Large doses may injure an animal, but if given as free cetraric acid it passes through the stomach unchanged to become slowly and completely dissolved in the intestine. The mucous membrane of the intestine of animals that had been treated with an overdose was found to be richer in blood, so that Kobert assumed that cetraric acid would be useful in assisting digestion. There is also the possibility that the lichen acid inflamed the sensitive mucous membrane. By means of acetone, *d*-usnic, evernic, and obtusatic acids have been

extracted from *Ramalina calicaris* (13). The last-named acid was the same as "Makao" obtained from the Manchurian drug "Shi-hoa."

Lichens, with two exceptions, are nonpoisonous, though some acid substances in others may be irritating when taken internally. The poisonous exceptions are *Evernia vulpina* and *Cetraria pinastri*, both a characteristic bright yellow. The former contains vulpinic acid in the cortical cells, the crystals of which are yellow in the mass. The latter species and *Cetraria juniperina* Ach. produce pinastrinic acid in the hyphae of the medulla, the crystals being orange or golden yellow. These lichens have been used in northern European countries to poison wolves by mixing the lichens and powdered glass with the bait (18). Santesson isolated the crystalline acid and tested it on animals; it produced respiratory difficulties, reducing the rate of breathing until death ensued. Seshadri and coworkers extracted usnic and sekikaic acids from *Ramalina tayloriana* Zahlbr., which when tested on fish (*Haplochilus panchax*) proved lethal. D-usnic acid in running water (50 milligrams in hot absolute alcohol) proved toxic in 13 minutes; sekikaic acid in 100 milligrams per liter was effective in 27 minutes or in 6 minutes when the concentration was increased to 200 milligrams. It is further suggested by the authors that these lichen components may be equally toxic to living plant tissue when physical penetration is obtained by the lichen.

More recently a report of the Wyoming Agricultural Experiment Station, in a study of the presence of selenium in soil and various plants, states that *Parmelia molliuscula* Ach. contains this poisonous salt in sufficient quantities to affect sheep and cattle. It produces a lack of coordination of the hind limbs; in severe cases the animals are unable to move either hind or fore legs. Other examples of lichens containing such elements include beryllium in *Parmelia saxatilis* Ach. and *Xanthoria parietina* Th. Fr., chlorine in *Evernia furfuracea* (13).

Modern developments in lichenology.—Employment of lichens as raw materials in pastries, confectionery, foods, and in the production of alcohol depends largely on the properties of "lichen starch." The presence of a certain number of phenols, acid-phenols and acid-phenol-ethers, together with other substances in the extracts of some lichens, forms the basis of their use in perfumery and cosmetics. The tinctorial properties of lichens are for the most part derivatives of orcinols, as in species of *Roccella*. Besides possessing lichenin and isolichenin and the sugar alcohols such as erythritol and manitol, lichens have as their most characteristic components the lichen acids which seem to be built on an altogether original pattern. In the past 50 years more than 200 of these lichen-acid compounds have been isolated. These compounds are, for the most part, known only from the class Lichenes and were originally thought to be peculiar to them alone.

Raistrick (15) introduces new findings, however, remarking that the isolation of two lichen acids, parietin and physcion, from the lower fungi is an “. . . observation . . . of some biological interest since . . . (it) gives strong evidence for the view that the so-called lichen acids owe their origin to the fungal half of the fungus-alga symbiont. . . . The presence of chlorine containing metabolic products (of the Lower Fungi) emphasizes the close metabolic relationship between moulds and lichens, since two of the very few organic chlorine-containing substances occurring in nature have been isolated from lichens, i. e., gangaleoidin and diploicin.” Research on lichen acids began with the Germans—Zopf, Hesse, Fischer, and others—but received most attention from the work and simplified methods of extraction of Asahina and his Japanese colleagues. These studies are being conducted today by Rao, Sastry, Seshadri, and Subrumanian, of Andhra and Delhi Universities, India; by Robert L. Frank and his students at the University of Illinois; by F. Bustinza and C. Lopez, Madrid, Spain; by the workers at University College, Dublin, under the late Prof. T. Nolan—Breaden, Davidson, Hardiman, Jones, Keane and Murphy—and V. C. Barry, all of whom are contributing detailed information on the chemical constituents of the lichens in their respective areas. The research of these workers is basic to the recent experimental aspects of lichenology. In view of present-day research, this information has passed from the sphere of academic interest and begins to assume real value in practical application as well as presenting a more complete understanding of the biology of this group of plants.

Since the discovery of the chemotherapeutic effects of penicillin, the phenomenon of antibiosis has attracted widespread attention and stimulated the investigation of other plant groups. Some investigators (2), studying the antibiotic activity of lichens, proceeded with their studies because: “In view of the reported antibacterial activity of the green alga *Chlorella* and the many antagonistic substances now known to be produced by numerous kinds of fungi, the lichens seemed to offer favorable material for antibiotic investigations inasmuch as the bodies of these plants are comprised of mixtures of algae and fungi.” Using the cylinder plate procedure, they analyzed the antibacterial activity of extracts from 42 species of lichens, later extending the work to 100, of which 27 species were found to be active against *Staphylococcus aureus* and *Bacillus subtilis*, while 2 species inhibited the growth of *Proteus vulgaris* and 2 species showed slight inhibition against *Alcaligenes fecalis*; none of the lichen extracts used in the test showed antagonism against *Escherichia coli*. That more than one antibiotic compound may exist in lichens is suggested by the fact that both *S. aureus* and *B. subtilis* are inhibited by extracts from *Cladonia grayi*, *Parmelia physodes* and other lichens, while substances obtained from some spe-

cies of *Cladonia* inhibited *B. subtilis* but not *S. aureus*. Extracts from *Cladonia furcata* Schrad., *Cl. papillaria* Hoff., and *Umbilicaria papulosa* inhibited *S. aureus* but were inactive against *B. subtilis*. Furthermore, the inhibition of some Gram-negative bacteria by selected species of lichens lends further support to the theory of multiple substances. The authors pose the question: Do the characteristic lichen acids possess antibacterial activity or are the antibiotic properties of lichens related to traces of other unidentified substances synthesized by these plants? Burkholder and his associates noted that some of the lichen compounds possess certain structural features in common with antibacterial substances isolated from molds, but they could not be sure that these were responsible for the antibiotic phenomena observed. They point out the fact that "almost nothing is known about the anabolism of the components or the roles of the various substances formed in the lichen body." In a subsequent report, Burkholder and Evans (3) reach the conclusion that "the phenomenon of antibiosis . . . is well exemplified in the lichens." These antibiotic substances are apparently different from penicillin, for the activity of several species of lichens was not lost after boiling in Na_2CO_3 solution. Samples of lichens collected from different regions showed, on the whole, characteristic activity in antibiotic tests with suitable bacteria. No explanation is offered for the variability, though there may be some relationship between this phenomenon and the fact that some of the diagnostic lichen acids vary in different samples of some lichen species. Though diagnostic compounds known to occur in the antibiotic species of *Cladonia* are listed, the authors suggest that other unidentified substances might be responsible for the observed antibacterial properties. The presence of antibacterial substances in numerous species of *Cladonia* and in representatives of other genera of lichens appears to be definite, but whether these are bacteriocidal or merely bacteriostatic is not proved. Although Gram-positive bacteria, including several pathogenic types, are inhibited, Gram-negative bacteria, with a few exceptions, are generally not susceptible to the antibiotic substances of lichens.

Other research (1a) on antitubercular compounds indicates another promising possibility for a lichen compound. Numerous acids were the subject of synthetical studies by various workers in the field of antitubercular compounds. Barry began with roccellic acid isolated from *Lecanora sordida* Th. Fr. The author states: "We have already reported that this substance in the form of its half-esters or half-amides inhibits completely the growth of the tubercle bacillus *in vitro* at a dilution of about one five-hundred-thousandths." Barry adds that "the most active of these compounds are at the moment being tested in animal-protection experiments, and although they are strongly antagonized by serum *in vitro*, they seem to have some activity in the animal."

The original work of Burkholder and Evans in 1945 has stimulated other investigations into the antibiotic phenomena of lichens. Thus Stoll, Brack, and Renz (19b, 19c), working with 58 species from different genera, report that 38 have been found to have antibacterial action in vitro against *Staphylococcus aureus*. The active principles have been proved to be lichen acids of which *l*-usnic acid is reported to be active not only against *Staphylococcus* but also *Mycobacteria*, *Streptococcus*, *Escherichia*, and *Eberthella*. F. Bustinza and A. Caballero Lopez (3a) verify some of the earlier studies. Usnic acid again appears as the more active substance against *Staphylococcus* and *Mycobacterium*; the lichens used were *Usnea barbata*, *Evernia furfuracea*, and *E. prunastri*. Dr. Bustinza reports (in correspondence) a paper to appear in Endeavour on "Antibacterial Substances from Lichens."

INDUSTRIAL USES OF LICHENS

Brewing and distilling.—Use of lichens instead of hops for the brewing of beer has been mentioned as having occurred in one or more monasteries of Russia and Siberia which had a reputation of serving bitter and highly intoxicating beer to the traveler. Tuckerman further describes a byproduct of *Lobaria pulmonaria* Hoff. which was used as "a yellow, nearly insipid mucilage which may be eaten with salt."

Alcohol production from lichens is an old art, now replaced by increased cultivation of potatoes, importation of sugar, and distillation of wood. Preparation of spirits from lichens was recommended in 1870 as a means of saving grain otherwise diverted into alcohol production. It was claimed that 20 pounds of lichen would yield 5 liters of 50-percent alcohol. Stenberg (20) published a report in Stockholm in 1868 on the production of lichen brandy, and included detailed plans for setting up a distillery with figures of possible production levels. By 1893 the manufacture of brandy from alcohol derived from lichens had become a large industry in Sweden, but by 1894, as a result of the local exhaustion of the plants, the industry languished. Arendt (13) in 1872 reported that this originally Swedish discovery was being applied in the Russian provinces of Archangel, Pskow Novogorod, etc., and that various distillers exhibited samples of lichen spirits at the Russian Industrial Exhibition in Moscow, which were highly approved by the French and English visitors. The industry was a lucrative one in the northern provinces of Russia, yielding a net revenue of from 40 to 100 percent. Others (6) have reported on the carbohydrate composition of lichens on the Kola Peninsula, considered in connection with the problem of glucose production in northern localities. This includes a tabulation of carbohydrates present in eight lichen species, which shows them to be rich in polyhexoses, but poor in cellulose and in pentosan. Two small

factories in Kirovsk have demonstrated the possibility of subjecting lichens to preliminary treatment with weak alkali solution in order to convert the bitter-tasting lichen acids into soluble form. This is then hydrolyzed with dilute H_2SO_4 , neutralized with chalk, and purified with activated charcoal to produce a molasses containing 65 to 70 percent glucose. From this, crystallized (lump) glucose was obtained. The yield of molasses was 100 percent, based on dry lichen weight. However, molasses produced by this process from lichens of the *Cladonia* group, especially *alpestris*, has a bitter taste, "the cause of which the authors are investigating."

Lichens vary in the amount of carbohydrates (lichenin) present. *Cetraria islandica* and *Cladonia rangiferina* have been found to yield up to 66 percent of polysaccharides which are readily hydrolyzed to glucose and then almost completely fermented to alcohol. Besides sugars capable of fermentation, lichen acids up to 11 percent of air-dried substance may be present. These acids as well as sodium chloride have been found to retard the process. Experiments with *Cladonia rangiferina* have shown a total yield of 54.5 percent sugar which on fermentation produced 176 to 282 cubic centimeters of alcohol per kilo. Maximum returns of alcohol were obtained by steaming the lichens 1 hour under the three atmospheres pressure, adding 25 percent HCl, resteaming for the same period of time and pressure, and finally neutralizing the product. Subsequent growth of yeast was normal, though fermentation could be accelerated by addition of H_3PO_4 . An interesting modification of this procedure through addition of three parts by weight of H_2SO_4 and one part by weight of NaCl at room temperature gave a pentanitrate similar to cellulose nitrate which, on gelatinizing with a solvent, produced a substance resembling horn (13).

Tanning.—The tanning quality of lichens is due to an astringent property (depsides) peculiar to some species. *Cetraria islandica* and *Lobaria pulmonaria* are most frequently used, and, though not occurring in quantities sufficiently large to warrant industrial application, have been locally employed on a small scale.

Dyeing.—Synthetic dyes have largely replaced many formerly common vegetable dyes in the textile industry, primarily because of their low production cost and the fact that they generally surpass the natural products in fastness, particularly light fastness. Of the vegetable dyes, those obtained from lichens were renowned among the peasant dyers of old for their high quality and color, but today are the least known. Some of them are still popular in rural districts of Great Britain and the Western Islands, Iceland, Scandinavia, France, and Germany. Interest in lichen dyes is being revived today somewhat in Scandinavia because of their use by the Hemslöjd (Home Industries Association), while there is some indication that the Irish

Government is trying to reestablish this art in the poorer farming and fishing districts where these skills have been lost. That there is a good economic reason for such revival may be noted by the fact that the production of Harris tweed, originally dependent upon lichen dyes, is a carefully organized industry in Great Britain producing a luxury cloth of standard quality and great demand. The most attractive feature of home-dyed and woven cloth is not only the dye utilized in its manufacture but also the individuality of the patterns evolved by a particular household or community. When these are standardized, as they may be through government and association intervention, they lose much of their appeal to the retail trade. Under such controls, prices tend to rise in excess of the true value, even for handicraft. It has been observed that wool dyed with lichen dyes is not attacked by cloth moths, which accounts in part for the durability of this cloth.

In response to a query, the Harris Tweed Association, Ltd., reported in 1948 that "just prior to the war a certain amount of the dye used in making the crotal shade (brown) of Harris tweed was produced from lichens but during and since the war economic conditions have altered so quickly that the dyeing of crotal by lichens has decreased. It takes a person nearly a whole day to collect sufficient lichens to dye 50 to 60 lbs. of wool." The Imperial Institute reports that the use of lichens for this purpose has practically ceased. From 1925 to 1939 a considerable expansion took place in the Harris tweed industry, primarily in the export trade; the decreasing availability of lichen dyes made it imperative to use other dyes. "In recent years the crofters have realised the ease with which synthetic colors can be employed and they buy in small quantities direct from the dye-stuff makers. There are now four fairly substantial dye-works in Stornoway and these only use commercial synthetic colors; logwood and fustic are the only natural colorings still employed." Kemp, Blair & Co., Ltd., of Galashiels, Scotland, contributed a note of further interest: "Considerable knowledge existed in the Hebrides with regard to the use of other vegetable growths such as heather tips and roots, but the quantities of these in use . . . could be considered practically negligible. It is likely that the quantities of Crotal used will gradually increase again but it is doubtful if it will ever again regain its prewar quantity."

Mairet (13) states that none of the great French dyers used lichen dyes, nor are they mentioned in any of the old books on dyeing. Yet Amoureux, Hoffman, and Willemet (13) published simultaneously in 1787, giving directions and samples with color names of lichen dyes as used by the French "tinctures" of their day, reflecting in part the universal application of these plants. Westring's (22) treatises on this subject, published from 1791 to 1806 in Sweden, are collectors' items, containing hand-colored plates of the lichens and small water-

color panels illustrating the colors obtainable. These works established their author as an authority, and he is the source of information in later numerous and often unacknowledged studies. Westring's system of the classification of lichen dyes distinguishes between lichen dyes which impart color to pure water (essential pigments) and those requiring certain treatment to yield color (preparable pigments). Lebail (13) in 1853 and Lindsay (11) in 1854, as well as others, classified lichen dyes according to the color produced, recognizing, however, that color varied with treatment.

History.—Of all the lichen dyes used by man, none has attained greater historical and commercial importance than those of the Roccellaceae, variously known to the English as orchella moss, orchella weed, orchil paste or orchil liquor, to the French as orseille, and to the Germans as persis. Orchil and cudbear are preparations of lichens and not the actual plants. Lindsay (12) states that:

We may practically regard Orchil as the English, Cudbear as the Scottish, and Litmus as the Dutch name for one and the same (?) substance. The first being manufactured in the form of liquid of a beautiful reddish or purple colour; the second in the form of a powder of a lake or red colour; and the third in that of small parallelopipeds or cakes of a blue color. The commercial or trade designations of the dye-lichens depends upon the thallus being erect or pendulous, cylindrical or shrubby or flat, crustaceous, foliaceous, and closely adhering to the substrate. The former are "weeds" (*Roccella*); the latter are "mosses" (*Lecanora* and *Parmelia*).

The attempt to combine trade names and utilitarian characteristics with imperfectly known taxonomic features produced these peculiar groupings of widely different species.

Theophrastus and Pliny appeared to have been familiar with the dye of the Roccellaceae, while a Biblical reference has their origin in the "Isles of Elisha." During the Middle Ages the art of making this dye fell into disuse, and it disappeared from the markets of the world until the seventeenth and eighteenth centuries, when it again took on the aspects of an industry, and the "weed" became an article of international exchange comparable to spices. Lindsay was particularly interested in the commercial aspects of lichens. His recommendations for a fuller investigation of the subject throws some light on the economic aspects of lichens in trade. He indicates that the field is comparatively new, and open to many possibilities, especially if the lichen resources of Scotland were exploited. "The speculation (investment?) of substituting home for foreign dye lichens promises to be remunerative as the roccellas have frequently reached the high price of £1,000 per ton in the London market." In 1855 he reemphasized that "if commanders of ships were aware of the value of these plants, which cover many a rocky coast and barren island, they might with a slight expenditure of time and labor bring home with them such

a quantity of these insignificant plants as would realize considerable sums, to the direct advantage of themselves and the shipowners; and consequently to the advantage of the State." He even compromised the reforms of social revolution with the possibility of financial returns, saying that "indirectly, a multiplied trade in dye-lichens might scatter the seeds of civilization, and place the means of a comfortable subsistence at the command of the miserable inhabitants of many a barren island or coast, at present far removed from the great centers of social advancement . . ."

Blue and red dyes.—An interesting etymological and historical note upon the derivation of the word "Rocella" has been contributed by Woodward (23). In this is cited early references to *archil* and *orchil* in Shakespeare's "Richard II and III," and it is implied that the Spanish terms *orciglia* or *orchillia* and the Portuguese *urzela* were probably derived earlier from the Italian. From a privately printed history of the Florentine family Rucellai, Woodward noted a statement that the family name was derived from "the art of the lichen dye"; this was also spelled Oricellai. The Oricellai or Rucellai were dyers in the twelfth and thirteenth centuries. About that time one of the family traveling in the Levant succeeded in obtaining technical information on the preparation of the lichen dyes, which made possible the establishment of the industry in Florence and the beginning of a monopoly that persisted until the discovery of the Cape Verde Islands. The botanical term was first used by Linnaeus for *Lichen roccella*, which de Candolle adopted for the genus *Rocella* as it is known today; the Rocellaceae include lichens furnishing blue and red dyes. The first source of supply in the Levant and Mediterranean countries was controlled by the Rucellai and other merchants of Florence. Discovery of new lands broke this monopoly and revealed the abundance of the plants on rocks along warm seacoasts. The trading centers became, successively, Portugal, France, and Holland. De Avellar Brotero (5) of Lisboa wrote in 1824, referring to the dye, that "its uses have been much extended for it serves as pigment to dye wool, silk, cotton, and various other fibers, it serves in paints, to color marble, wines, liqueurs, papers, pills, oil, grease, wax, etc." New sources for the "weed" were found in the Cape Verde Islands, Cape of Good Hope, Angola, East Africa, Mozambique, Madagascar, Zanzibar, Ceylon, the East Indies, Australia, Valparaiso (Chile), Lima (Peru), and the west coast of North America. Shiploads of it were gathered from Lower California and adjacent islands.

The species which constitute the commercially valuable orseille lichens have been grouped as follows into orseilles of the earth (A)

and orseilles of the sea (B), with the most important marked by an asterisk (16):

Dye lichens and their sources

Locality	Type	Species
Pyrénées, Alps, Cévennes (France).	(A)	<i>Pertusaria dealbata</i> Cromb.
Auvergne (France)-----	(A)	<i>Lecanora parella</i> Ach.
Sweden-----	(A)	<i>Lecanora tartarea</i> (L.) Ach.
Norway-----	(A)	<i>Umbilicaria pustulata</i> (L.) Hoffm. and other <i>Umbilicaria</i> sp.
Canary Islands (Atlantic Ocean)-----	(B)	<i>Rocella tinctoria</i> Lam. & DC.
Madeira (Atlantic Ocean)-----	(B)	<i>Rocella tinctoria</i> Lam. & DC.
Mogador (North Africa?)-----	(B)	<i>Rocella tinctoria</i> Lam. & DC., <i>Ramalina scopulorum</i> Ach., and others.
Manila (Gorée) (Philippine Islands).	(B)	<i>Rocella portentosa</i> Mont.
Sardinia (Mediterranean)-----	(B)	<i>Rocella phycopsis</i> Ach., <i>Rocella tinctoria</i> Lam. & DC.
Angola (Africa)-----	(B)	<i>Rocella Montagnei</i> Bél.
Valparaiso (South America)-----	(B)	<i>Rocella portentosa</i> Mont.
Ténérife (Canary Islands)-----	(B)	<i>Rocella tinctoria</i> Lam. & DC.
Mozambique (East Africa)-----	*(B)	<i>Rocella Montagnei</i> Bél.
Madagascar (Indian Ocean)-----	*(B)	<i>Rocella Montagnei</i> Bél.
California (North America)-----	*(B)	<i>Dendrographa leucophaea</i> (Tuck.) Darb.
Cape Verde Islands (Atlantic Ocean).	*(B)	<i>Rocella tinctoria</i> Lam. & DC.

Importers of old were always reluctant to disclose the origin of their best supplies, but *R. tinctoria* of the Cape and South America was "6-8 inches long and as thick as goosequills" and so regarded highly by the dye merchants (13). In 1750 the Cape Verde and Canary Islands exported 100 tons annually to England. By 1818 the cost had jumped from £40 to £200 per ton, depending on the quality, but in 1886, with a stable supply from Ceylon where *R. tinctoria* grows abundantly on palms, the price settled at £50 per ton. Specimens of *R. fuciformis* DC. were exhibited at the London Crystal Palace in 1851, at which time the price quoted was £380 per ton. The latest figures available list the importation of tanning and dyestuffs into England for 1935 (13) as annatto, 837,919 pounds; brazilwood, 854,581 pounds; lichen dyestuffs, 411,265 pounds.

The chemical components of lichen dyes were not understood in the early development of the lichen dye industry. The method of preparing the dye and its application was traditionally maintained by small groups as close trade secrets. The accessibility of new sources of the raw material did not necessarily affect these secrets, for the lichen dye had first to be prepared. The article of commerce was in

paste form, and it was in this manner that other nations obtained their dye from Florence until they succeeded in obtaining the formula for making it, and developed the skill for preparing it. In the old English method the lichen was cut small or reduced to a powder by passing it through a sieve, and placed in iron drums provided with paddles. The mass was moistened slightly with stale urine, the mixture being stirred once a day with additions of soda for 5 or 6 days at a temperature of 35° to 45° C. Fermentation proceeded and was checked frequently until the coloring matter, a dove gray, ceased to increase. The product, orchil paste, was then placed in wooden casks and covered with lime water or gypsum solution until needed by the dyer. To make orchil liquor the lichen was treated with water and urine and permitted to ferment as for orchil paste, after which the fibrous matter was removed and the liquor collected and stored. Sal ammoniac and saltpeter were sometimes used in the process. Dillenius, 1741, "reckoned [the color] more beautiful when first dyed, than the Tyrian Blue," while Bancroft (13), in 1832, described the infusion of orchil as of a red crimson inclining to violet.

Modern methods are based on more accurate knowledge of the chemistry of the lichen dye. According to Hill (13), the lichen is sprayed with ammonia until the mass turns color, when the blue orchil liquor is extracted with water; if heated until the ammonia is driven off, red orchil results; afterward the plants are dried and ground to a fine powder.

The French employed a crustaceous species commonly called "perelle" to obtain a purple-blue dye. M. Cocq, in the eighty-first volume of the *Annales de Chimie*, describes its preparation as observed at Clermont, France. The lichen was macerated in wooden troughs, 6 by 3 by 2 feet, and fitted with tight covers. Two hundred pounds of perelle and 240 pounds of urine were mixed in the trough and stirred every 3 hours for two successive days and nights, care being taken to keep the covers closed to avoid loss of the volatile alkali (ammonia). On the third day, 10 pounds of sifted, slaked lime were added and well mixed with a quarter-pound of arsenic and an equal weight of alum. The mass was then stirred several times, once every quarter-hour, later every half-hour, until fermentation was established, to prevent the formation of a crust on the surface of the mass. Fermentation was renewed by adding 2 pounds of sifted lime, and stirring once every hour for 5 days. On the eighth day it was stirred every 6 hours, and the processing might extend a fortnight to 3 weeks. The coloring matter was kept moist in closed casks until used. It was said to improve the first year, to suffer little change during the second year, and to begin to deteriorate in quality during the third year of storage.

Bancroft recommended the use of ammonia instead of urine, and of hogsheads to facilitate agitation; the addition of arsenic and alum he

considered useless and dangerous. Use of human urine was commonplace, since it was the only early source of ammonia, and Lindsay (12) states that manufacturers recognized different qualities of it in producing the coloring matter: "Hence, I have been informed that some English manufacturers who continue to use this form of ammiacal solution, have learned by experience to avoid urine from beer-drinkers, which is excessive in quantity but frequently deficient in urea and solids, while it is abundant in water."

Brown and yellow dyes.—Employment of brown and yellow dyes is an old custom in the northern countries of Europe. Fries remarked on the use of the class Lichenes in the arts "that almost all that is known has been owing to the Northern—the Anglo-Saxon, Scandinavian and German—Nations whom necessity constrained to value all of Nature's gifts." In certain districts of Scotland, as Aberdeenshire, almost every farm or cotter had its tank or barrel ("litpig") of putrid urine ("graith") wherein the mistress of the household macerated some lichens ("crotals" or "crottles") to prepare dyes for homespun stockings, nightcaps, or other garments. The usual practice was to boil the lichen and woolen cloth together in water or in the urine-treated lichen mass until the desired color, usually brown, was obtained. This took several hours, or less on the addition of acetic acid, producing fast dyes without the benefit of a mordant or fixing agent. The color was intensified by adding salt or saltpeter. This method was prevalent in Iceland as well as in Scotland for those home-spuns best known to the trade as Harris tweed.

Campbell, in the National Geographic Magazine, February 1947, states that in the Hebrides "lichens from the rocks supply a dye of misty brown, but the fishermen do not use this color while in their boats believing that what is taken from the rocks will return to the rocks." Horwood (13) reported that in the Shetlands the lichens were harvested in May or June, or after rain in the autumn or winter, a metal scraper being used for rock species. They were washed, dried in the sun, and sometimes powdered, and were processed and shipped in casks to the London market as cudbear. This term is derived from a corrupt pronunciation of the name of Dr. Cuthbert Gordon, chemist of Glasgow, who obtained a patent for his process of preparing the dye from *Ochrolechia tartarea* on a large scale. One person could collect 20 to 30 pounds daily, any one locality being visited every 5 years. After washing and drying, the collected weight was reduced to half.

Hooker (*in* Lindsay (12)) records that in 1807 at Fort Augustus a person could gain 14 shillings per week by collecting cudbear, estimating a market price at 3 shillings 4 pence per stone weight (22 pounds). Other observers have recorded it as an article of commerce about Taymouth, in Perthshire, in North Wales, Derbyshire, Westmoreland, and

Cumberland at 1 shilling 1 penny per pound in 1854, while the manufacturers of woollens and silks paid 10 shillings a hundredweight for it with a profit of 8 pence to the middleman. The manufacture of cudbear flourished about Leith and Glasgow because *Ochrolechia* (*Lecanora*) *tartarea*, from which it was prepared, first came from the western Highlands and islands around Scotland and was a chief source of revenue to the "poor Highlanders" whose other source of income, gathering seaweed for potash salts, ceased. The value of this lichen to Scotland was said to have averaged £10 per ton, though other species, as *Parmelia perlata* Ach., sold at from £190 to £225 per ton in 1851. The manufacture of cudbear moved into the hands of English orchil makers who imported their materials from Norway and Sweden for the London market. From 1785 to 1788, 24,000 kilos were shipped from Flekherjored, Norway (9).

For home use (see p. 419) the cotters would mix the crotals treated with graith into a coarse paste rolled into small balls or cakes with lime or burnt shells. These were wrapped in dock leaves and hung up to dry over peat fires, which accounts for the peat-smoke odor peculiar to homespun Harris tweed. In this fashion the dye would keep for a year or more; when needed, it was redissolved in warm water.

The colors of cudbear and of orchil are so similar as to be commercially indistinguishable. They dye best in a neutral bath producing a bluish-red or dull magenta shade but are frequently applied with sulfuric acid in conjunction with other vegetable dyes and coal-tar dyes, especially magenta. Addition of indigo and the dye of lungwort gives a permanent black dye. *Rocella tinctoria* was used as the first dye for blue British broadcloth, having a purple tint against light. A variety of colors and shades can be obtained by the use of different species of lichens, varying the treatment with oil of vitriol, logwood, or chemicals. Thus acids produce yellows, alkalies produce blues, lead acetate gives a crimson precipitate, calcium chloride a red precipitate, stannous chloride a red then yellow, while alum is more generally used by country folk for reds. The color of cudbear is said to possess great beauty and luster at first, but quickly fades and should never be employed unless for the purpose of giving body and luster to blue dyes, as indigo ("bottoming"), or as a ground for madder reds (12). In deep shades the color has an intensity and body that cannot be equaled by coal-tar substances, and though they are not fast to light, milling, or scouring, they do resist soaping but become bluer. Silks, and occasionally linens, have the dye applied in a soap solution with or without acetic acid.

Cudbear and orchil have both been used in Holland for the manufacture of litmus, known to the French as tournesol. After the dye

is prepared, gypsum or powdered chalk is added and then cast into small, purplish-blue cubes, once sold as lacunus. This, dissolved in water and soaked up in unsized paper, was retailed as litmus paper. This early product was rather unstable and tended to become colorless. The action is thought to be due to micro-organisms, so that alcohol or chloroform was often added when the litmus was stored in liquid form. Tincture of cudbear was still used in the drug trade up to 1942 when the Dutch source of supply was no longer available and the U. S. Pharmacopeia recommended a coal-tar derivative, amaranth.

Carlos Tavares (Portugal) has informed the author that "in some regions of our country lichens are yet employed for dyeing clothing; I think *Lobaria pulmonaria* one." A specimen of *Usnea dasypoga* from Ecuador collected by Inez Mexia (7913) bears the annotation "a brown dye is made by boiling with lemon." A report (3b) of Australian aboriginal names and uses of plants indicates that lichens were not used in the native economy.

The chemical properties of dye lichens are better understood today because of the studies of the workers, previously listed. A comprehensive survey of lichen compounds may be found in Thorpe's Dictionary of Applied Chemistry, 4th ed., vol. 7, p. 284.

COSMETICS AND PERFUMES

History.—Since the sixteenth century, or earlier, members of the families Cladoniaceae, Stictaceae, Parmeliaceae, and Usneaceae have been utilized as raw materials in the perfume and cosmetic industries. At first this use consisted of drying and grinding the plants to a powder and combining them crudely with other substances, but as the manufacturers became more expert in their trade, these materials were skillfully combined into toilet powders, scented sachets, and perfumes of real value. Three lichens commonly used were *Evernia prunastri*, *E. furfuracea*, and *Lobaria pulmonaria*, which have similar aromatic substances. The trades recognized these lichens under a variety of names, as Lichen quercinus viridis, Muscus arboreus, acaciae et odorante, Eichenmoos, and, more commonly, as Mousse de Chêne or oak-moss and scented-moss. *Ramalina calicaris* Fr. was used in place of starch to whiten hair of wigs and perukes. Cyprus powder, a combination of *E. prunastri*, *Anaptychia ciliaris*, and *Usnea* species, was scented with ambergris, or musk, and oil of roses, jasmine, or orange blossoms for use as a toilet powder in the seventeenth century that would whiten, scent, and cleanse the hair (19). After a somewhat lengthy eclipse, these plants reappeared as raw stuffs for perfumery, owing to the creation of scents with a deep tone and to the demands for the very stable perfumes of modern extraction, to which purposes they are almost universally applied to this day.

The principal species used in modern perfumes and cosmetics include *Evernia prunastri*, *E. furfuracea*, *E. mesomorpha*, *Ramalina fraxinea* Ach., *R. farinacea*, *R. pollinaria* Ach., and perhaps other species of the Ramalinae, though the last-named genus is not rated as so valuable as the former. *Lobaria pulmonaria* (Mousse de la base du Chêne) is used to some extent and is considered a more costly substance, perhaps because of its relative scarcity. Oak-moss (*E. prunastri*) of Europe is collected in shaded, damp habitats occurring in the central mountain ranges of Europe, the Piedmont of Italy, and the forests of Czechoslovakia and Herzegovina. Not only the locality but the substratum is given a great deal of attention by the perfumer who differentiates between those plants that grow on oak (greenish) and those found on conifers (grayish); in the latter case rightly so, since resins may be included with the lichen, rendering it less desirable for the trade. In all instances the crop is gathered by peasants or shepherds, as in Yugoslavia, and pressed into large bales for export. The American supply before the war was derived from Yugoslavia, amounting to a few tons yearly at a cost of from 5 to 7½ cents per pound f. o. b. New York City. During the war a few companies, formerly established in France and Holland, became interested in developing the American market, but the lack of apt collectors willing to work for wages per pound equivalent to or slightly higher than those of the European gleaner rendered the commercial possibilities for the use of American plants somewhat doubtful. Experiments, including a number of North American species, have been carried out with little success, except with those traditionally used in the Old World. Of these there are sufficient quantities available in the northern forests of the United States and Canada to supply the domestic trade.

Chemical properties of essential oil of lichens.—The use of dried, pulverized oak-moss in the perfume industry is restricted, the principal sale being of extracts, essences, and resinoids. Gildermeister and Hoffmann (13) state that the method of treatment involves exhausting the lichen by means of volatile substances and then removing the resins, waxes, and chlorophyll with acetone. Addition of alcohol gives an "extract of oak-moss" which may be used in this form or may be further concentrated in order to obtain a semifluid substance. French and German industrial research during the last 30 years has revealed much of the chemical nature of the extracts, gums, and mucilages produced when processing lichens. Gattefossé (13) made a study of the essential oils and alcoholic extracts of all those lichens that were utilized as oak-moss, obtaining data that caused him to conclude that oil of oak-moss was almost exclusively a compound of phenol called lichenol, an isomeric compound of carvacrol. These results were verified by St. Pfau (13) who further expressed the opinion that sparrassol, a metabolic product of the fungus *Sparassis*

ramosa, is identical with methyl everninate resulting from the alcoholysis of everninic acid, present in proportions of about 2.8 per cent, with a characteristic anise-seed odor. Walbaum and Rosenthal (13) repeated the experiments of Gattefossé and arrived at different results. They distilled the oil of *Evernia prunastri* and found that at ordinary temperature it formed an oily crystalline mass of dark color with a very powerful and agreeable odor. Further analysis revealed Gattefossé's error, and orcinol monomethylether, not lichenol ($C_{10}H_{14}O$), is the principal constituent of oak-moss. This phenol, though not the main odoriferous part of the lichen oil, has a pleasant, creosol-like smell, and an ester β -orcinol methyl carboxylate ($C_{10}H_{12}O_4$) which does not enter into the odor of the oak-moss oil. In the resinous precipitate Walbaum and Rosenthal found ethyl everninate generated only during the extraction through esterification of the everninic acid ($C_{17}H_{16}O_7$) which was found to occur in a free state in the lichen; when boiled with baryta water it split into orcinol and everninic acid with the liberation of carbon dioxide. This acid is closely related to β -orcinol monomethylether and would be converted into it by the liberation of carbon dioxide. For these reasons Walbaum and Rosenthal felt that the genesis of the principal constituent of the odoriferous substances of oak-moss had a close connection with the origin of everninic and evernic acids. Stoll and Schener (13) found in the volatile fraction some compounds which may also have a function in producing this odor, mainly thujone, naphthalene, borneol, camphor, civeole, citronellol, guaniol, vanillin, methylnonylketone, and stearic aldehyde.

The multiplicity of types of essences and extracts may be due in part to the diversity of substrata on which these lichens grow, as well as to the varying mixtures of species offered to the manufacturer in any lot, and the mode of extraction. This is also verified by the theory of multiple substances in lichens, as proposed by Burkholder and Evans (3). Hess (13) was able to extract atranorine and everninic acid from a specimen of *Evernia prunastri* growing on oak, but not from samples collected on beech or birch, while a sample from a lime tree yielded some usnic acid. The whole problem is further complicated by the fact that most constituents of oak-moss react upon the solvent. Treatment of lichen extracts with alcohol is seldom employed for preparation of essences, since it alters the evernic acid. Thus the lichenol obtained by Gattefossé, using this method, was everninate of ethyl. The synthesis of everninic, divarine, and other acids has been performed in the laboratory but has not been applied on a commercial scale. In the trade the oil is extracted by means of low-boiling solvents, after which it is purified and decolorized, the process yielding 0.2 to 0.3 kilo of the raw extract or 20 to 30 grams

of the pure essential oil, depending on the technique of extraction in which 100 grams of the dried lichen yield 8.5 grams of crude everninic acid.

Uses of essential oils.—The essential oil of oak-moss or “concrete” is used in its natural condition in soap as an impalpable powder or in the form of a resinarome. The powder permits production of soap balls agreeably scented at a reasonable price if the manufacturer can obtain a perfectly impalpable powder; otherwise they give the impression of containing sand. The soap manufacturer maintains the quality of his product by procuring his raw material from a reliable purveyor. To be sufficiently scented, soap balls should have 1 or 1½ percent by weight of lichen powder. When used for this purpose oak-moss “concrete” improves, strengthens, and cheapens lavender-scented products. It is essential in the higher grades of cosmetics in combination with other aromatic oils, e. g., jasmine, tuberose, and orange blossom. Iceland moss, *Cetraria islandica*, has already been mentioned in connection with foods and medicine; in the field of cosmetics it serves as a source of glycerol in the soap industry and in the manufacture of cold creams because of its lack of odor. Some lichens, e. g., *Sticta fuliginosa* Ach. and *S. sylvatica* Ach., have an objectionable fishy or methylamine smell.

The parfumeur recognizes abstract qualities in lichens which enhance his product. The peculiar reciprocity of the components forming the lichen unit and known to the unromantic biologist as symbionts, are but an example of harmonious blending appreciated by the parfumeur. Therefore the extract of oak-moss or scented-moss “agrees” and “harmonizes” in the “happiest manner” with a large number of other essences. Its fragrance has been likened to musk-lavender, and as such it may be used as a fixative of the poppy type, blending well with bergamot, citron, acetate of linalyl, and linalol, thus supplying freshness; with neroli, jasmine, rose, and cassia it improves the flavor of these flowers; it gives flexibility to tarragon, coriander, portugul, ylang-ylang, and vanillin; contributes stability and depth to patchouli, vetyver, coumarin, and musk, and “elevation” to alpha ionene. It also blends well with synthetic oils, e. g., amyl and isobutyl salicylate and acetophenone. It is considered as an indispensable basis of numerous perfumes known to the trade as Chypre, Fern, and Heath, and in many bouquets called “Fancy,” as well as for the Oriental type of perfume. The absence of aromatic oils, glycerol, or any other desired substance is no disadvantage for the use of lichens in cosmetics; *Cladonia rangiferina* and *Cl. sylvatica* have been recommended by parfumeurs, since they are whitish, easily dried, and abundant “in open healthy places.”

MISCELLANEA

Gums.—The dyeing and paper industries have need for quantities of sizing with which to dress and stiffen silks, to print and stain calico, and to size paper. During the Napoleonic Wars, because of the French monopoly of Senegal gum, Lord Dundonald attempted to introduce the use of lichen mucilage in place of the French product, but there is no evidence that the English market was interested. At Lyons the French appear to have successfully used lichen mucilage as a substitute for gum arabic in the fabrication of dyed materials (13). The problem has been investigated by Minford (13) who reports that Iceland moss and some other lichens may be prepared as light-colored, transparent, and high-grade gelatin, isinglass, and similar gelatinous products, corresponding to those obtained from vegetable products for this purpose.

Lichens for decorations.—The use of lichens for home decorations, funeral wreaths, and grave wreaths is commonly exploited in the northern countries of Europe, partly as a result of tradition and the expense of out-of-season flowers. The Cladoniaceae or reindeer lichens lend themselves best to this purpose and are always used in centerpiece table decorations in winter and in connection with Christmas ornaments. In older types of Swedish houses, where the outer or storm window can be separated from the permanent window, the space between at the base is filled with this lichen which may act partly as insulation. Dry lichens are brittle and are usually gathered and worked in the fall of the year when the air is moist; they are woven into wreaths by the poorer farming class who offer them for sale on market days at low prices. Addition of water, as for cut-flowers, does not preserve them but tends to make them moldy. Lichens can maintain themselves on hygroscopic water. The harvesting of lichens, especially *Cl. alpestris*, can be a source of considerable revenue. In 1935, 2,900 boxes (orange-crate size) were exported from Norway. In 1936, 7,700 boxes were shipped, and in 1937, 12,500 boxes which yielded a revenue of 90,000 Norwegian kroner (\$1.00=4.90 Norw. kr., August 1947). Later shipments went only to Germany, and the Göteborgs Handels-Och Sjöfarts-Tidning (newspaper) published a story on October 12, 1946, entitled "Fjällresa Med Linné," which said that this lichen export was being used by the Germans as a source for "explosives." The Germans had an essential need for this plant also as grave decorations. The gathering of these lichens for decorations is cause for further dispute between Lapp herders and commercial harvesters. *Cladonia* species are occasionally used in table models and dioramas to represent trees.

In northern or mountainous areas where forest cover exists, it is possible to estimate the normal depth of the snow cover by noting the

height of certain brown parmelias growing on trees, particularly birches, as these lichens are sensitive to prolonged snow cover and quickly disappear from those parts of the tree covered by accumulative or drifting snow falls. Thus it would be possible to judge not only general but specific localized snow depths for estimating watershed and irrigation potentials, and probable snow falls in mountain passes, and to assist in railroad engineering problems relative to the location of snow sheds, and in highway maintenance and the temporary location of snow fences.

Injury by lichens.—Lichen injury to valued stained-glass windows of old cathedrals and to marble, alabaster, and Florentine mosaics has been reported by various observers (13). The deleterious effect of *Parmelia tinctorum* Despr. upon a Buddhist monument in central Java is given by Seshadri and Subramanian (18a). Chemical analysis of this specimen revealed a high percentage of atranorin (20.3); the authors suggest that this water-soluble acid is capable of causing damage to calcareous substrates. E. Bachmann (13) had earlier published a series of observations (1904–15) upon the action of lichens on mica, garnet, quartz, and calcareous rocks indicating that the first two substances were rapidly decomposed while calcareous rocks were dissolved through the action of the lichens. The more resistant quartz was minutely etched. Bachmann concluded that lichens exert a mechanical and chemical action on their substrate, and that they must give out solvent acids in the process. Orchardists and silviculturists have long been interested in the relationship of lichens to trees, and many sprays, including Bordeaux mixture, caustic soda, and light-boiling tar oils, have been recommended for the removal of these “unsightly if not injurious plants.” Indirectly they may be the cause of economic loss by serving as shelter for harmful insects seeking cover and depositing eggs. Kaufert has noted that the bark of *Populus tremuloides* remains permanently smooth through the presence of a persistent periderm, but that if injured by fungi, lichens, or mechanical injury the bark may be stimulated to develop rough fissures. In studying the influence of *Usnea* species upon trees in South Africa, Phillips (13) concluded that in this case the lichen is definitely detrimental in that its fungal component is parasitic upon tissue external or internal to the cork cambium. Vigorous crowns as well as defective ones may be infected. Since the lichen cannot develop luxuriantly under the conditions obtaining in undisturbed high forests, he recommended that the forest canopy be preserved as a means of inhibiting the rampant growth of this lichen. Seshadri and Subramanian (18b) present more definite evidence of lichen damage to trees. In this instance it was noted that the more tender portions of sandalwood trees bore heavy growths of lichens which appeared to affect the normal development of the tree. The principal lichen, *Ramalina tay-*

loriana, had penetrated deeply into the viable tissues of its substrate causing apparent physical injury. On analysis, this lichen gave *d-usnic* and *sekikaic* acids which had a proved toxic effect on fish used in experimentation. The suggestion is advanced that the deep penetration of the lichen base into the viable sandalwood tissue may have resulted not only in physical injury but in a phytocidal effect. Wellborn (13) suggested that some leaf spots of the coffee plant may be caused by a lichen, and the classical research of Ward (21) on *Strigula complanta* Mont. illustrates the undeniable harmful effect of a lichen epiphyte on a crop plant. Leaf lichens are common on evergreens, deciduous trees, and bushes in the sub-Tropics and Tropics, but unless the leaves of such phanerogams have a commercial application, as tea leaves, there is no economic loss involved. Foresters in some parts of Europe recommend scraping lichens from trees, but there is little experimental proof that lichens epiphytically attached to the bark, branches, and twigs of trees are the cause of damage. Howbeit, the whole problem of whether lichens injure the trees on which they are fastened cannot be solved, as Elias Fries once remarked, "by mere denial."

DYEING INSTRUCTIONS FOR HOME USE (10)

Parmelia saxatilis.—The Swedish country people call this the dye-lichen or stone-moss. It occurs abundantly on rocks and stones as rugose gray-brown patches, and should be collected after rain while the air is still moist, for it is firmly attached to the stones and will crumble if removed in dry air. It is most easily separated from the stones by an ordinary table knife, and if it is to be preserved it must be carefully dried before being packed in bags or boxes. Before use it should be finely crushed. The following colors may be obtained by varying the dyeing treatment:

1. Light yellow-brown.—Place 1 kilogram (2.2 pounds) of finely crumbled dye-lichen in a copper kettle containing a large quantity of water. Place 250 grams⁷ of unmordanted (raw) yarn in this solution, boiling and stirring the yarn for ½ to 2 hours, depending on the desired shade of color. The best method of stirring the yarn is to wind it around sticks so as to avoid cloudy or uneven dyeing. When the process is completed, the yarn should be washed thoroughly in several changes of clean water, after which it may be hung up to dry, making sure that the skein hangs freely.

2. Dark brown.—The lichen is crumbled and placed in layers with wool or yarn in an iron kettle. The yarn should be wet when put down, and after addition of cool water in sufficient quantities to cover the mass, several hours should lapse before boiling. Boiling must be slow and regular with constant stirring for 2 to 6 hours. If a very

⁷ 1 ounce=28.35 grams; 1 pound=0.45 kilogram.

dark color is desired, the yarn may be boiled again in a fresh quantity of the dye-lichen. If the desired color is black-brown, some braziline (brazilwood chips) should be added. If dark brown color tones are desired, best work with gray yarn. Wash as above.

3. Rusty brown.—Ingredients: 250 grams of yarn, 40 grams of alum, 15 grams of tartar, 2 kilograms of lichen.

The yarn is mordanted in alum and a solution of tartar $\frac{1}{2}$ to 1 hour. The lichen is boiled in a large quantity of water for 1 hour, after which the mordanted yarn is added and then boiled for 2 hours. The best method is to have the hanks strung on sticks. If the yarn is not turned over maculation will result. If a red tone is desired, the yarn should be removed from the kettle and boiled half an hour in a solution of 30 grams of soaked madder. Wash as above.

4. Dull brown.—Use four times as much crumbled lichen as yarn by weight and soak in water 1 day before boiling. Then boil for 1 hour. Add a solution of soap to the unmordanted yarn and boil another 2 hours, then permit it to cool. Remove the yarn and wash as above.

Cetraria islandica.—This lichen, commonly known as Iceland moss, grows abundantly in woods and in the mountains. It is loosely attached to the ground, and is best collected in dry weather so as to save the trouble of artificial drying before storage for winter use. Before using place it in fresh water for softening, after which it is easy to chop up. Like the dye-lichen, it gives beautiful brown colors but in different shades, and has been found to be of value in dyeing suede, since it produces the faint pastel tints desired by the trade (19a).

1. Brown.—The lichen is cleansed, washed, and finely crumbled before being placed in a kettle; layers of wool or yarn should be alternated with lichen. Water is added and all is boiled half an hour. Iron vitriol should be dissolved in warm water and carefully added to the mass. This is boiled slowly and stirred constantly until it is sufficiently dark. Wash as above.

Usnea barbata.—This is the beard-lichen and occurs abundantly in woods, growing on both coniferous and foliaceous trees and wooden fences, hanging down as a light gray beard. The lichen is branched, soft, and elastic, and when it is pulled out the outer crust bursts and a white horsehair-shaped inner tread is left. When collected, this lichen should be separated from needles and twigs. It gives a fine red-yellow color.

1. Red-yellow.—Ingredients: 250 grams of yarn, 32 grams of alum, 250 grams of beard-lichen.

The yarn is, as usual, mordanted with alum. Boil the beard-lichen 1 hour and strain off, adding the yarn to the solution and boiling for

$\frac{1}{2}$ to 1 hour, depending upon the desired shade of color. Lighter shades are obtained by using weaker solutions.

Alectoria jubata.—The color of the horsehair-lichen is gray-brown or black. It grows commonly on old coniferous trees, hanging down from the twigs in long tufts. Its branches, when pulled, do not behave as do those of the beard-lichen, but, like that lichen, it gives a yellow-brown dye, though of a different tone.

1. Yellow.—Follow the instructions as for the beard-lichen. The darkest shade will be mellow green-yellow. By diluting the solution lighter tones of a fine cream-yellow may be obtained. Wash as above.

Notice! For obtaining lighter shades of colors the yarn must be boiled six times in weaker solutions. It is not advisable to use stronger solutions for shorter times. This rule can be generally applied in all cases.

ACKNOWLEDGMENTS

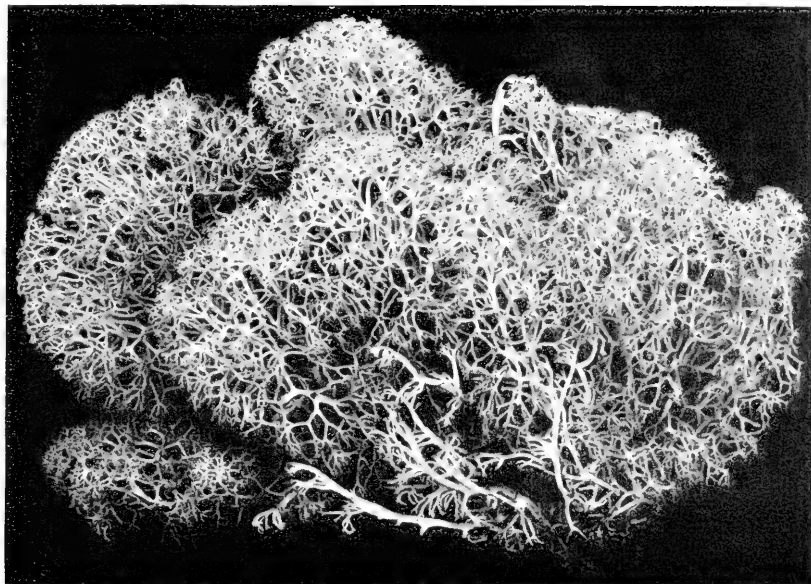
The author is greatly indebted to Dr. G. Einar Du Rietz, Director of the Plant Science Institute, Uppsala, Sweden, for the many courtesies received as a student at that Institute; to Dr. Gunnar Degelius for advice and the generous loan of his valuable collection of books and duplicates; to Dr. Rolf Santesson of the Institute for Systematic Botany for his assistance; to Dr. Magnus Fries for the use of the Th. M. Fries Lichenological Collection; to Dr. A. H. Magnusson for the use of his library; and to the librarian of the Carolina Rediviva, Uppsala University, for many favors. The author expresses his appreciation also to the American-Scandinavian Foundation, New York City, for the Fellowship which made it possible for him to study at the Royal University of Uppsala, Sweden, from 1946-47; and to Dr. C. W. Dodge, Missouri Botanical Garden, for his kindness in checking the final manuscript of this article.

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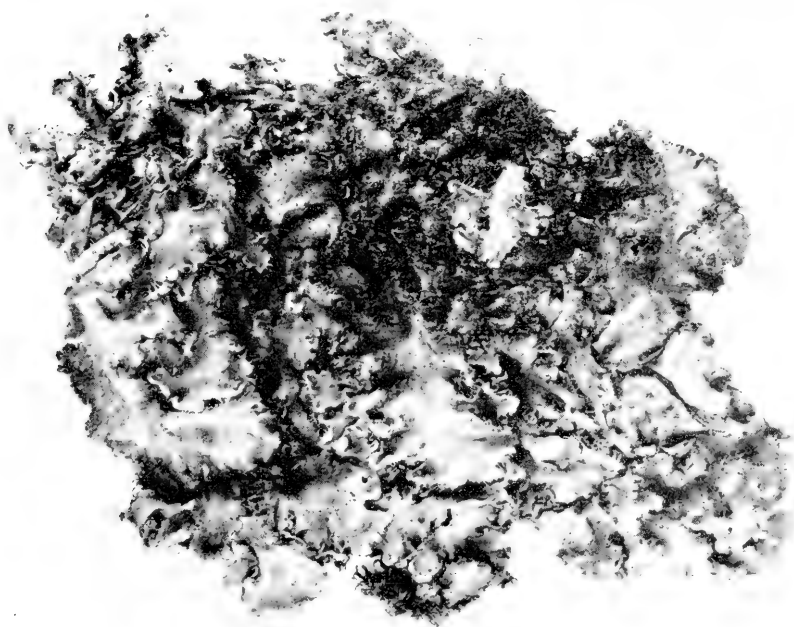
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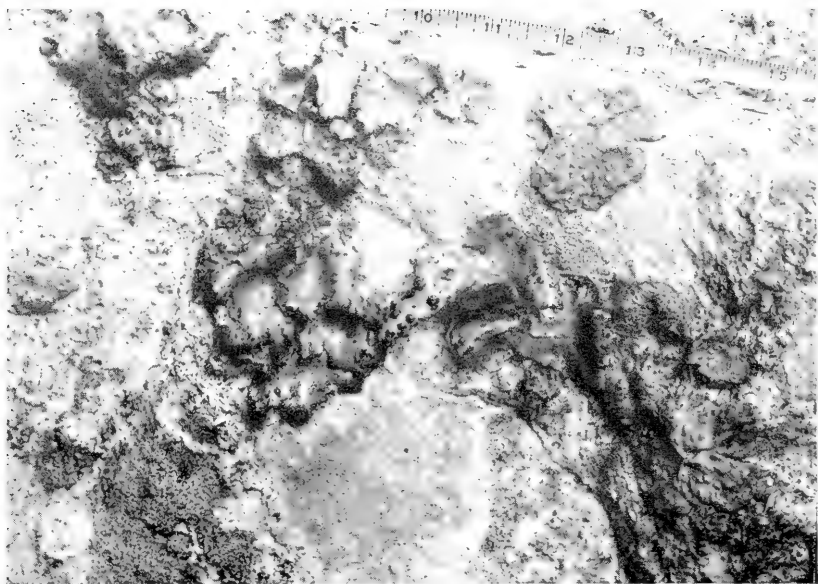
1. REINDEER MOSS, *CLADONIA ALPESTRIS* AND *CL. RANGIFERINA*

These species constitute the principal food of reindeer and caribou herds. (Courtesy New York Botanical Garden.)



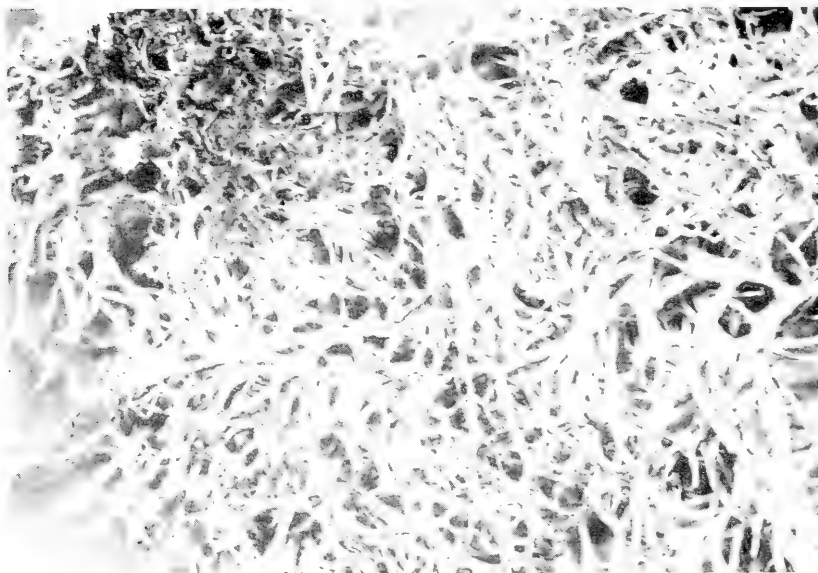
2. DOG LICHEN, *PELTIGERA CANINA*

Preparations of this lichen were regarded in the Middle Ages as efficacious in treating rabies. (Courtesy New York Botanical Garden.)



1. ROCK TRIPE, *UMBILICARIA PAPULOSA*, WITH PUSTULES ON ITS UPPER SURFACE AND TWO OTHER SPECIES OF *UMBILICARIA* ON THE ROCK

This and other kinds of rock tripe, *Gyrophora* sp., have been used by polar explorers as emergency food.



2. *EVERNIA FURFURACEA*, SHOWING UPPER AND LOWER SURFACES OF THE THALLUS

Mount Desert Island, Maine.



1. REINDEER PAWING AWAY SNOW COVER TO OBTAIN LICHEN FODDER, LAPPLAND, SWEDEN

(Photograph by G. Haglund.)

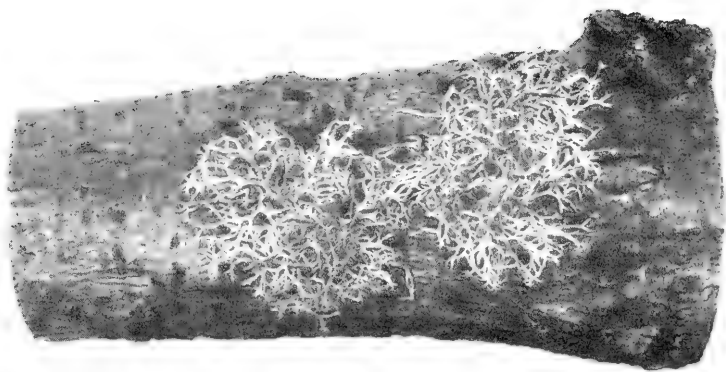


2. REINDEER SUMMER FEEDING IN LAPPLAND, SWEDEN

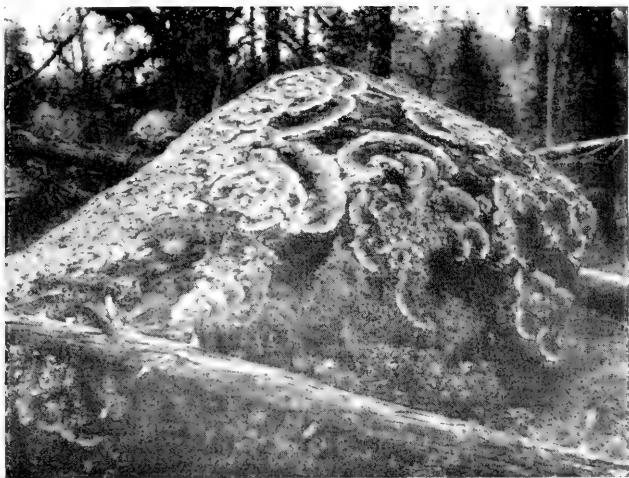
(Courtesy Swedish Railways.)



1. BEARD LICHEN, *USNEA* SP., GROWING ON BIRCH
Mount Desert Island, Maine.

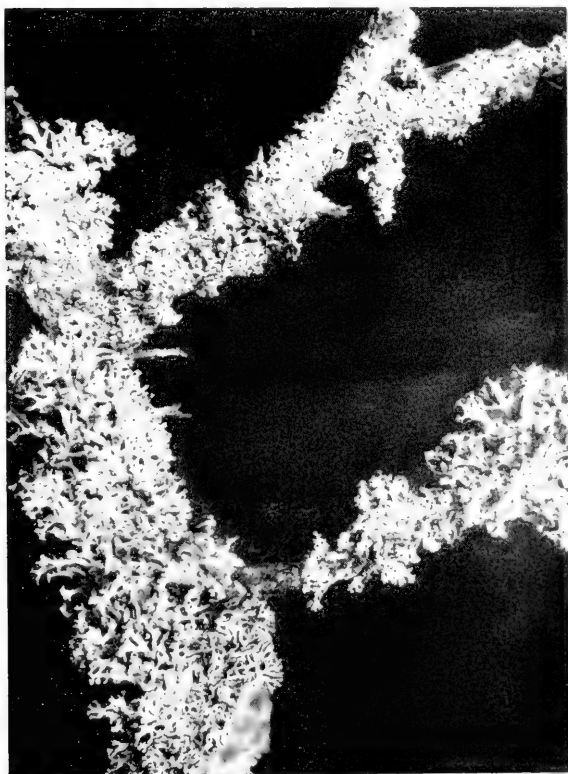


2. *EVERNIA PRUNASTRI* ON A TREE TRUNK
(Courtesy New York Botanical Garden.)



1. *PARMELIA SAXATALIS* ON THE LOWER SIDE AND *P. CENTRIFUGA* ON THE UPPER SIDE OF A ROCK

(Photograph by Auer, Finland.)

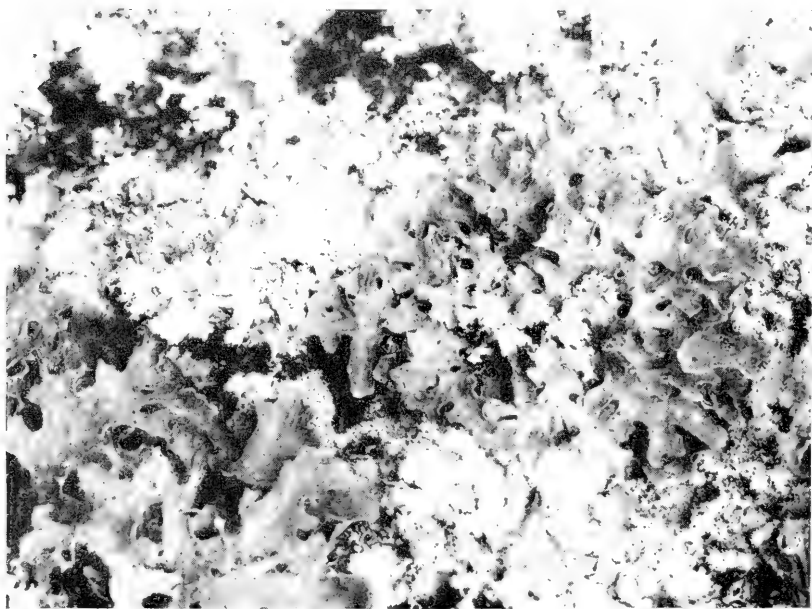


2. *PARMELIA PHYSODES*, SHOWING ITS DENSE GROWTH ON THE BRANCH OF A PINE TREE

Mount Desert Island, Maine.

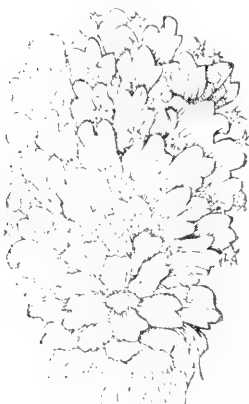


1. CLADONIA ALPESTRIS (IN CLUMPS) AND CL. RANGIFERINA (NOT IN CLUMPS)
ON MOUNT DESERT ISLAND, MAINE



2. LOBARIA PULMONARIA GROWING WITH LIGHTER-COLORED FORMS OF PARME-
LIACEAE ON A TREE TRUNK
Mount Desert Island, Maine.

ILUSTRADO POR EL DOCT. LAGUNA.
LICHEN. PALMONARIA. 407



PALMONARIA.



Del Lichen. Cap. LIV.

EL Lichen que nace en las piedras, llama lo *Dioscori* de algunas librys, hallase apogado a las piedras húmedas como el mazgo de los arboles. Este pues aplicado en forma de emplastro, refina las estufiones de fangre, reprime las inflamaciones, y es remedio de los empeynes. Si se aplica con miel, tiene fuerza de fimar la ístericia, y refrena los humores que corren aza la lengua, y la boca.

Gr. y Xps. La. Lib. 7. Ar. Auger. Alfocher. B. He. Nombres.

patina. It. Epatica F. Heparquet. T. Steinfelcherkrant.

EL empeyne se llama Lichen en Griego; y así *Anazarbo* vino a llamarle Lichen esta planta, porq̃ cura de Laguna

los empeynes aplicada en forma de emplastro, o

porq̃ se citiende a manera dellos sobre piedras.

Produce las hojas gruellas, grañas, llenas de ymo,

y como ahojaládradas vnas sobre otras, de

las quales salen ciertos talluelos, como pezones

q̃ producen encima de si vnas cabeçuelas, a ma-

nera de estrellas, principalmente en el mes de

Junio. Nace esta por la mayor parte sobre las

piedras. Otra especie de Lichen semejante a esta

pero mas ancha y mas seca, se halla sobre las en-

cinas y robles, la qual por parecerse a vn pulmón

se vino a llamar Pulmonaria. Algunos confiados *Pulmonaria*

en solo el nombre, la dan contra las llagas de los

pulmones. Tiene cada vna de las facultad de mu-

ltificar, y de resfriar moderadamente con estir-

richidad manifestada, de do se puede conjeturar, q̃

possee virtud de soldar las heridas frescas, y cor-

rectar las llagas antiguas.

De la Paronychia. Cap. LV.

Esta Paronychia es vna macilla pequeña, q̃ nace sobre las piedras, semejante al *Pepto*, anoz *Dioscri* de algunas librys, aplicada en forma de emplastro, sana los *paronychia* y *les des*.

Paronychia es vna macilla pequeña, q̃ nace sobre las piedras, semejante al *Pepto*, anoz *Dioscri* de algunas librys, aplicada en forma de emplastro, sana los *paronychia* y *les des*.

Paronychia es vna macilla pequeña, q̃ nace sobre las piedras, semejante al *Pepto*, anoz *Dioscri* de algunas librys, aplicada en forma de emplastro, sana los *paronychia* y *les des*.

Paronychia es vna macilla pequeña, q̃ nace sobre las piedras, semejante al *Pepto*, anoz *Dioscri* de algunas librys, aplicada en forma de emplastro, sana los *paronychia* y *les des*.

Illustration of page 407, second edition of Andres de Laguna's "Pedacio Dioscorides Anazarbeo," published by Juan Latino, Anno MDCV, Salamanca, Spain. Now the property of the Bibliotheca Nacional, Madrid. (Courtesy Dr. F. Bustinza.)



Upper: Helmslöjd group near Uppsala, Sweden, with paraphernalia for dyeing with lichens collected in the immediate vicinity. The equipment consists of iron and copper pots heated over wood fires, chemicals, and accessory dyes, and a small scale.

Center: Rinsing procedure, utilizing clean stream water. The white yarn is undyed and has been washed; the dark yarn has been dyed.

Lower: Drying the yarn after dyeing and washing (foreground). Undyed yarn hung up for convenience in handling (background).

THE ORIGIN AND ANTIQUITY OF THE ESKIMO

By HENRY B. COLLINS

Anthropologist, Bureau of American Ethnology

[With 4 plates]

Though numbering less than 40,000, the Eskimos occupy almost half of the world's Arctic coast lands. Beginning at the northeastern tip of Siberia, their scattered settlements extend eastward for more than 6,000 miles along the Arctic and sub-Arctic coasts of Alaska, Canada, and Greenland. No other primitive people occupy so wide a territory and at the same time exhibit such remarkable uniformity of language, culture, and physical type. Where Eskimo and Indian meet, as on the rivers of Alaska and in the interior of northern Canada, the culture and physical type of both groups have been affected. But nowhere have the Indians penetrated to the Arctic coast. Here, where the Eskimos hold undisputed possession, there is one language and, with certain exceptions to be noted later, one basic culture and physical type.

The origin of the Eskimo and his peculiar culture has been debated for many years. Probably the majority of American anthropologists in the past have accepted the theory that the Eskimos are an American people and their culture an American product. Boas, who studied the Baffin Island and Hudson Bay tribes, considered that the original Eskimo homeland was the lake region west of Hudson Bay. Here, said Boas, the Eskimo race and culture were found in purest form, unmodified by Indian influence; moreover, the traditions of the Eskimos to the east, north, and west all pointed to an original center just west of Hudson Bay. Murdoch, Wissler, Stefansson, Jochelson, Shapiro, and others followed this view, which, principally because of the great influence and authority of Boas, became in America at least the orthodox and "scientific" theory of the origin of the Eskimos.

Among European scholars who adhered to the American origin theory were Rink and Steensby. According to Rink, the early Eskimos lived in the interior of Alaska. From this center they had followed the Alaskan rivers to the coasts, their culture meanwhile undergoing gradual change until it developed finally into the typical maritime form we know today.

A more elaborate theory was advanced by Steensby, who postulated a stratification of Eskimo culture. The oldest stratum was that found

in the central archipelago of Canada, the high Arctic culture typified by the snow house, the dog sled, and various ingenious methods of hunting on the sea ice. This complex was "an outgrowth of an original North Indian form of culture, the winter side of which had become specially and strongly developed by adaptation to the winter ice of the Arctic Ocean" (Steensby, 1916, p. 186). Steensby thought that Coronation Gulf was the region where this adaptation had taken place. Belonging to a later stage were such features as kayak hunting on the open sea, the umiak, whaling, and the bird dart. These elements, lacking among the Eskimos of the Central regions, were characteristic especially of sub-Arctic Alaska and Greenland.

The latest and most comprehensive expression of this viewpoint is that of Birket-Smith (1929, 1930, 1936). His theory, though corresponding essentially with Steensby's, is considerably more elaborate and detailed. Birket-Smith believes that the Eskimo culture originated in the Barren Grounds west of Hudson Bay and that the Caribou Eskimos now living there are the direct descendants of the "Proto-Eskimos." Isolated in the interior, the Proto-Eskimos, like the modern Caribou Eskimos, lived by hunting the caribou and by fishing in lakes and rivers, in winter through holes in the ice. Later some of them—the "Palae-Eskimos"—moved to the seashore and learned to hunt seals by what is known as the "maupok" method, harpooning the seals at their breathing holes in the ice. The conversion of ice fishing into seal hunting on the sea ice was thus the first and most important step in the formation of Eskimo culture. Birket-Smith's theory has been summarized as follows:

Originally the Proto-Eskimo lived inland from Hudson Bay and farther west. Whereas some of them, of whom the Caribou Eskimo are the last survivors, remained on the Barren Grounds, others resorted to the coast between Coronation Gulf and the Boothia peninsula, where they adapted their living to the sea and were thus enabled to spread along the coast; this is the so-called Palae-Eskimo stage. At a later period the far richer Neo-Eskimo culture came into existence in Alaska; it spread as far to the east as Greenland, but at present it is not known from the central regions except from the so-called Thule culture which was brought to light by the archeological investigations of the Fifth Thule Expedition, being otherwise obliterated by a modern Eschato-Eskimo advance of inland tribes that penetrated to the sea and constituted the recent Central Eskimo. [Birket-Smith, 1930, p. 608.]

The opposite, or Asiatic, theory of the origin of the Eskimo has also had numerous supporters. First to express this opinion were the early explorers, who observed that the Eskimos had a distinctly Mongoloid appearance. Most of the nineteenth-century anatomists and anthropologists classified the Eskimos with the Asiatics, and later anthropologists such as Furst and Hansen, Hrdlička, and Hooton have concurred in this viewpoint. Ethnologists and archeologists such as Thalbitzer, Hatt, Bogoras, Kroeber, Mathiassen, Jenness, and Zolo-

tarev believe that Eskimo culture is essentially a product of the Old World. Students of Eskimo linguistics—Thalbitzer, Sapir, Bogoras, Jenness—all seek the origin of the language in Alaska or Siberia rather than in Canada or Greenland; and Sauvageot and Uhlenbeck have gone further and claimed a relationship between Eskimo and Ural-Altaic or Indo-European, the two major language stocks of the Old World. As will be shown later, the more recent archeological and somatological evidence confirms this point of view and seems to point conclusively to Eurasia as the place of origin of the Eskimo culture and race type.

The theory that has aroused more discussion perhaps than any other is that which derives the Eskimos from the Upper Paleolithic cave dwellers of western Europe. Boyd Dawkins and Sollas, the principal champions of this view, pointed to numerous resemblances between Eskimo and Paleolithic implements and art which they interpreted as evidence that the Eskimos were the actual descendants of Paleolithic man who had followed the reindeer northward at the close of the Glacial period, and at a later time spread eastward to Bering Strait. Physical evidence in support of the hypothesis was brought forward in 1889 by Testut, who claimed that a Magdalenian skull found in a rock shelter near Perigueux in the commune of Chancelade, France, could scarcely be distinguished from that of an Eskimo.

The theory of a racial or cultural connection between Eskimo and Paleolithic man has been opposed by a number of authorities though in later years it has received the support of Sullivan, Morant, and von Eickstedt. In general, the reaction of anthropologists has been one of skepticism or indifference, the prevailing attitude being that the idea was too spectacular and speculative to be scientifically valid. The postulated cultural connection seemed doubtful because some of the traits compared were of uncertain function; others were too simple and generalized or too widespread in their distribution to be indicative of a specific or exclusive relationship; and still others, as we now know, were traits characteristic of modern but not of ancient Eskimo culture. When Dawkins and Sollas wrote, there were no archeological finds from Siberia to bridge the enormous gap in time and space between Paleolithic man of western Europe and the modern Eskimo, nor was there any knowledge of prehistoric Eskimo culture. Now that excavations have been made in the American Arctic and Siberia, the postulated cultural affinities between Eskimo and Paleolithic appear in a different light. The recent excavations have produced new and unexpected evidence of relationship between the oldest Eskimo cultures, the early Siberian Neolithic, and the European Mesolithic (Collins, 1943). As the Mesolithic was a direct outgrowth of the Paleolithic, the Dawkins-Sollas theory may not have been so fanciful as it once seemed.

The archeological studies that have provided new insight into Eskimo culture began with those of Jenness (1925, 1928) and Mathiassen (1927) and have continued during the intervening years, the latest comprehensive works being those of Holtved (1944) in northwest Greenland and of De Laguna (1947) and Larsen and Rainey (1948) in Alaska. Important ethnological studies have also been made, and the same period has brought new information on the physical types of various modern and prehistoric Eskimo groups in Alaska and Canada. Though the recent investigations have provided the first factual data essential to an understanding of the problem of the Eskimo, it is not to be supposed that the final answers are at hand. For many parts of the American Arctic we still lack adequate information, and the recent discoveries have sometimes complicated rather than simplified the picture. In the following pages, after a brief summary of recent archeological discoveries and their implications, we shall attempt an over-all interpretation of the available evidence relating to the origin and affinities of the Eskimo race type and culture.

PREHISTORIC ESKIMO CULTURES

Thule.—Systematic Eskimo archeology began with the investigations of the Fifth Thule Expedition around Hudson Bay in 1922 and 1923 (Mathiassen, 1927). Excavating at old Eskimo sites north and west of Hudson Bay, Mathiassen uncovered evidence of a prehistoric culture that he called the Thule, which differed in many respects from that of the Eskimos now living in the region. The old Thule people lived along the seacoasts, in semisubterranean houses of whalebones, stones, and turf during the winter and in conical tents in summer. Unlike the modern Central Eskimos, the Thule people were whale hunters; they also hunted the walrus, seal, polar bear, and caribou. In material culture they differed markedly from the Central tribes, being much closer to the Greenland and Alaskan Eskimos. So close, in fact, were the resemblances to northern Alaska that Mathiassen was able to show that the Thule culture must have originated in the west, somewhere along the coasts of Alaska or Siberia north of Bering Strait. Having flourished for some centuries, the Thule culture disappeared from the Central regions, displaced and partly absorbed by the ancestors of the present Central tribes who moved from the interior out to the seacoasts. Meanwhile, the Thule Eskimos had moved eastward to Smith Sound in northwest Greenland. Excavations by Mathiassen, Larsen, and Holtved have traced in considerable detail the stages of development of Greenland Eskimo culture.

In West Greenland, the Inugsuk, a late stage of Thule culture dating from the thirteenth and fourteenth centuries, was in direct contact

with the medieval Norse settlements of Southwest Greenland. With this initial date established for the Inugsuk stage Mathiassen estimates that the Canadian Thule culture, which was ancestral to it, existed in the Central regions around A. D. 1000. There are also strong indications of a return movement of Thule culture to northern Alaska within the past few centuries.

Though it has played an important part in the formation of modern Eskimo culture from Alaska to Greenland, the Thule tells us nothing as to the origin of Eskimo culture. For this we must turn to the older stages—the Cape Dorset culture of the Hudson Bay region, the prehistoric Aleutian-Kodiak-Cook Inlet cultures of South Alaska, and the Old Bering Sea and Ipiutak cultures around Bering Strait.

Cape Dorset.—The Dorset culture was first described by Jenness (1925) on the basis of material excavated by Eskimos at Cape Dorset on the southwest coast of Baffin Island and on Coats Island in Hudson Bay. Dorset sites have now been found widely distributed in the eastern Arctic from Newfoundland north to Ellesmere Island and northwest Greenland (Jenness, 1933; Wintenberg, 1939; Rowley, 1940; Leechman, 1943; Holtved, 1944; Collins, 1950). Though the Dorset and Thule occupied the same general region, the two cultures differed from each other in almost every respect. At the Dorset sites there is no trace of such typical Eskimo elements as whale-bone mattocks and sled shoes, harness toggles, bone arrowheads, the throwing board, and harpoon sockets and finger rests. Completely ignorant of the bow drill, the Dorset Eskimos cut or gouged out the holes in their implements. Rubbed-slate artifacts, so common among other Eskimos, were very scarce as compared with implements of chipped stone. Distinctive types of harpoon heads, small ivory carvings and a simple geometric art style (pl. 1, a-f) are other features that characterize the Dorset culture. The Dorset people hunted walrus, seal, polar bear, caribou, hares, and foxes, but not the narwhal, beluga, or right whale. They had no knowledge of dog traction, though small hand sleds were used. As yet there is no definite information regarding their houses.

We know that the Dorset is older than the Thule culture because Thule implements are never found at pure Dorset sites, whereas Dorset objects frequently turn up in Thule sites. Moreover, at Inglefield Land in northwest Greenland, and at Frobisher Bay on Baffin Island, Dorset material has been found underlying Thule (Holtved, 1944; Collins, 1950). Inglefield Land is the only place in Greenland where the Dorset has been recognized as a distinct culture stage. There are indications, however, that the Dorset culture will prove to have been more widely distributed in Greenland than has been suspected. Solberg's "Stone Age" at Disko Bay (Solberg, 1907) is composed in large part of typical Dorset-type stone implements,

which probably indicate a Dorset stage of culture preceding the Thule on the west coast (Collins, 1937; 1940); and similar Dorset types from Ammassalik and the Clavering Island region, illustrated by Solberg (1932), Mathiassen (1933), and Larsen (1934), suggest that future excavations may also reveal a Dorset stage on the Greenland east coast.

In contrast to the Thule, the Dorset culture appears to be deep-rooted in the eastern Arctic. Its origin, however, is uncertain. On the one hand it shows affinities with Indian culture, particularly the Beothuk of Newfoundland and prehistoric cultures of the Northeast. More difficult to explain but undoubtedly significant are the close resemblances of some of the Dorset art motifs and stone-implement types to those of the Ipiutak, Old Bering Sea, and prehistoric Aleutian and Cook Inlet cultures of Alaska (pl. 1). The Dorset can hardly have been derived from any of the prehistoric Alaskan Eskimo cultures as we now know them, although a remote connection of some kind is indicated. The most likely explanation, as suggested by Jenness (1941), is that the Dorset has stemmed from the same parent trunk as the ancient Alaskan cultures. The many and fundamental differences between them, however, would indicate that the Dorset moved eastward to Hudson Bay before the Ipiutak and Old Bering Sea cultures had reached their full development.

It is probably significant that recent work in Alaska to be described below has revealed indications both in the interior and at Cape Denbigh on the Bering Sea coast of an ancient, apparently pre-Eskimo culture or cultures with definite Asiatic affinities, characterized especially by burins, by small lamellar flakes, probably used as knives or scrapers, and the polyhedral cores from which they were struck off (Rainey, 1939; Skarland and Giddings, 1948; Giddings, 1949; Solecki and Hackman, 1951). Lamellar flakes of the same kind are found at many Dorset sites, and Solberg's Disko Bay collection, which probably is Dorset, also includes a polyhedral core comparable to those from Alaska (Solberg, 1907, p. 39). There is also a strong probability that the stone burins from Giddings' Cape Denbigh site and two of the early inland sites in Alaska are related to a characteristic Dorset implement of somewhat similar form which De Laguna (1947, pp. 193-194) suggests were used as burins.

Birnirk.—The first excavations in the western Arctic were made by Stefansson in 1912 (1914). Digging in a large mound at an abandoned site called Birnirk near Point Barrow, Alaska, Stefansson noted the presence of clay pottery and unusual types of harpoon heads and the absence of such characteristic modern features as iron, soap-stone pots, pipes, net sinkers, and net gages. Wissler (1916), who described parts of Stefansson's collection, recognized the site as prehistoric but did not consider it to be especially old or to represent a

distinct stage of culture. Excavations at Birnirk and other nearby sites by Van Valin in 1918 and Ford in 1932, interpreted in the light of later information, have revealed the Birnirk as a key stage or link between the prehistoric cultures of Alaska and Hudson Bay (Mason, 1930; Collins, 1934, 1940).

The fact that the Birnirk resembled both the Canadian Thule culture and the Old Bering Sea, which was known to be older than Thule, suggested that it was the Alaskan stage ancestral to the latter. The indirect indications of this relationship were confirmed by excavations at Kurigitavik, a Thule-Punuk site at Cape Prince of Wales, Bering Strait, where a Birnirk to Thule sequence in harpoon heads was found (Collins, 1940).

Old Bering Sea and Punuk.—Evidence from St. Lawrence Island and Bering Strait indicates that the Birnirk in turn was somewhat later than Old Bering Sea. The Old Bering Sea Eskimos, like the Birnirk and Thule, were a maritime people who lived in permanent villages on the seacoasts and who depended for their livelihood on seals, walrus, fish, and birds. Whaling was practiced but only to a limited extent. Like the Dorset people, the Old Bering Sea Eskimos did not use the dog sled, though they had small hand sleds for hauling skin boats and loads of meat over the sea ice.

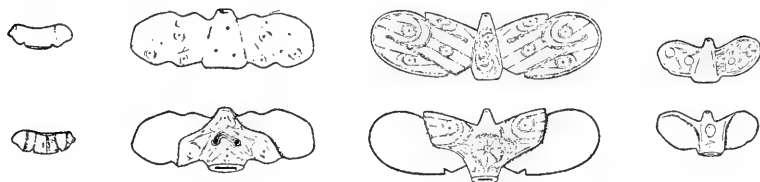
Living in a region abounding in game, and thus having an assured food supply, the Old Bering Sea Eskimos developed a rich and complex culture (Collins, 1937). One of its most striking characteristics was an elaborate and sophisticated art style. Ivory harpoon heads, knife handles, needle cases, and many other objects were not only skillfully carved but decorated with pleasing designs formed of graceful flowing lines, circles, and ellipses. On St. Lawrence Island stratigraphic excavations revealed three successive stages of Old Bering Sea art—style 1 (Okvik) (pl. 1, j–o), style 2 (pl. 2), and style 3 (pl. 3). Following these, there appeared a simpler style, the Punuk, which foreshadowed modern Eskimo art (fig. 1, lower half).

The Punuk culture as a whole was partly an outgrowth of the Old Bering Sea and partly the result of new influences from Siberia. Developmental changes in harpoon heads and other implements which began in the Old Bering Sea period continued throughout the Punuk. A number of completely new types also made their appearance in the foreshadowed modern Eskimo art (fig. 1, lower half).

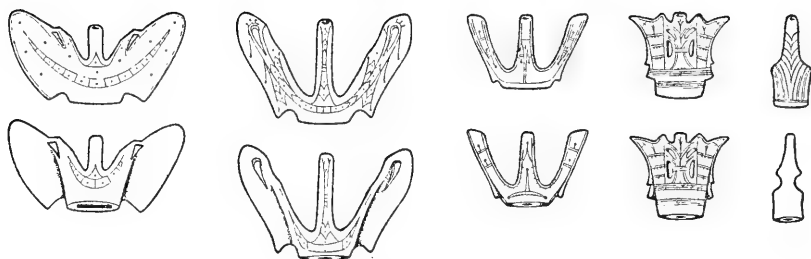
Though the Punuk was in all essential respects a stone-age culture, its art was the product of metal tools. This is evident from the appearance of the deeply and evenly incised lines and compass-made circles, and from the presence of small, slender engraving tools, several of which had bits of the iron points remaining in place. Stratigraphic and other evidence shows clearly that this metal long antedated the Russian period. Its source was probably eastern Asia

north of Korea where, from references in Chinese literature, we know that iron was in use as early as A. D. 262 (Collins, 1937, pp. 304-305).

We know that the Punuk was approximately contemporaneous with the Canadian Thule culture and somewhat later than the Birnirk. As yet there is no means of estimating the age of the Old Bering Sea



OLD BERING SEA



PUNUK

FIGURE 1.—Ivory winged objects and related forms of unknown use from St. Lawrence Island and Arctic coast of Alaska. Upper row shows the Old Bering Sea winged forms (both sides), the earliest, at extreme left, belonging to the Okvik stage. In the succeeding Punuk stage the wings became smaller and inclined sharply upward, resulting in trident and "turreted" forms on which only a vestige of the outer wings remained, and finally a bottle-shaped form, with no wings. All have a basal socket and a small pit at end of central projection. Approx. 1:7. (For description see Collins, 1937, pp. 197-201.)

culture, but a considerable antiquity is indicated by the magnitude of the deposits on St. Lawrence Island and by the long succession of cultural changes leading up to the Punuk. In the absence of any definite evidence, we may guess that the earliest Old Bering Sea remains may date from around the beginning of the Christian Era.¹ The Old Bering Sea and Punuk cultures are also found at Bering

¹ This paper was written before the results of radiocarbon dating had been announced. The provisional dates here mentioned for Old Bering Sea and other prehistoric Eskimo cultures and the relative chronological positions of these cultures are, with the exception of Ipiutak, those which I have given in earlier publications. The carbon-14 dates for several prehistoric Eskimo cultures have now been released though not formally published (Radiocarbon dates—September 1, 1950, by J. R. Arnold and W. F. Libby, Institute for Nuclear Studies, University of Chicago, 15 pp., offset). The age of Okvik, the earliest stage of Old Bering Sea culture, is given as 2,258 years \pm 230. Giddings' middle layer at Cape Denbigh, comprising types resembling Ipiutak, South Alaska, and Dorset, is 2,016 years \pm 250. Ipiutak itself is much younger than had been supposed, 912 years \pm 170 at Point Hope and 973 \pm 170 at Deering. Laughlin's "Palae-Eskimo" stage at Umnak Island in the Aleutians, equivalent to Hrdlička's "Pre-Aleut," is dated at 3,018 years \pm 230.

Strait, and sporadic traces occur in Arctic Alaska. Until recently adequate information was not available for northeastern Siberia, though scattered finds of Old Bering Sea and Punuk art and implements suggested that the two cultures may have occurred there in greater concentration than in Alaska. Proof of this seems to have been provided by two recent Russian publications. Matchinski (1941) has described two archeological collections from the Chukchee Peninsula containing a number of Old Bering Sea and Punuk objects, and Rudenko (1947) describes a large body of similar material from 12 village sites on the east and south coasts of the Peninsula. According to all indications, it is in northeastern Siberia, somewhere between the mouths of the Anadyr and Kolyma Rivers that we must look for the immediate origin of the Old Bering Sea culture.

Ipiutak.—The most remarkable and most puzzling of all prehistoric Eskimo cultures is the Ipiutak, discovered at Point Hope on the Arctic coast of Alaska in 1939 by Rainey, Larsen, and Giddings (Larsen and Rainey, 1948). The Ipiutak culture proper lacked such typical Eskimo features as pottery, lamps, sleds, and rubbed-slate implements, and possessed a wealth of curious ivory carvings and numerous other features unknown to other Eskimos. A single iron-pointed engraving tool showed that the Ipiutak people had knowledge of metal. A closely related phase, the Near Ipiutak, differed in that it possessed whaling harpoon heads, stone lamps, and possibly pottery and rubbed-slate implements. Typical of both phases were small, finely chipped stone blades as well as antler and ivory arrowheads and lances with rows of stone side blades which were similar to types from early Neolithic sites in Siberia. The significance of this will be discussed later.

Thus far the Ipiutak culture proper is known only from the type locality, a huge site of almost 600 houses on the gravel spit at Point Hope. Larsen and Rainey believe, nevertheless, that the Ipiutak Eskimos were essentially an inland rather than coastal people. The Point Hope site, they believe, was occupied only in summer, when the people came down to the coast to hunt sea mammals. They spent the winter in the interior hunting caribou, like the modern Nuna-tagmiut, their supposed descendants. It is indeed difficult to see how so large a settlement could have been occupied throughout the year because of the enormous quantities of driftwood that would have been required for fuel, as the Ipiutak people did not use blubber lamps. Thus far, however, no trace of Ipiutak has been found in the interior, despite the fact that Solecki (1950) and others have found over 300 inland sites, many of them along the headwaters of the Colville and on the Utukok, Kokolik, Kugurok, and Kukpowruk, streams not far inland from Point Hope and along which theoretically the Ipiutak people should have lived for many years. A few of these sites are

very old, being related to Giddings' early Denbigh Flint Complex, many are of undetermined age, and others are recent camp sites of the Arctic coast Eskimos who had gone inland to hunt caribou. This considerable body of negative evidence tends to weaken, though of course it does not disprove, the postulated inland affinities of Ipiutak. On the other hand, there is increasing evidence of Ipiutak at other coastal locations, for recent excavations by Larsen (1950) and Giddings (1949) have revealed sites with Ipiutak-like culture at Kotzebue Sound, Seward Peninsula, Norton Sound, and Kuskokwim Bay.

Despite its extreme specialization and divergence from other Eskimo cultures including Old Bering Sea, the Ipiutak has many features in common with the latter, and on the basis of actual correspondences in art and implement types is more closely related to it than to any other phase of Eskimo culture. Ipiutak art employed the same elements as Old Bering Sea, though in most instances the composition was somewhat simpler (e. g., pl. 1, q). A number of Ipiutak objects bear an ornamentation that is typical of Old Bering Sea style 1 (Okvik) and style 2 (pl. 2, a, b). And there are two artifacts—parts of ivory “winged objects” like the third figure in figure 1—which must be regarded as intrusive, as such objects are among the most striking and diagnostic features of the Old Bering Sea culture, but are not otherwise represented at Ipiutak. These two objects provide a relative *terminus a quo* for the Ipiutak culture, showing that the houses in which they were found could be coeval or later but not older than Old Bering Sea.

In addition to art, a number of Ipiutak implements, including complicated types of harpoon heads, adzes, arrowheads, bird-dart prongs, and snow goggles, are identical with or very similar to Old Bering Sea types. Ipiutak also shows significant resemblances to Dorset, to the prehistoric Aleutian and Cook Inlet cultures, and to that of the modern Eskimos of the Yukon-Bristol Bay area.

The Ipiutak flint industry is undoubtedly a survival from the Siberian Neolithic. However, Larsen and Rainey (1948) have shown that Ipiutak also had connections with Siberian bronze- and iron-age cultures of around the beginning of the Christian Era, from which they conclude “that the Ipiutak people at that time lived on the Arctic periphery of these culture centers” (p. 160). The original homeland of the Ipiutak people, they believe, was along the lower Ob and Yenesei Rivers, and their culture has such close parallels in this and adjacent regions that “it has not flourished very long on American soil.” Postulating a short interval between the time the Ipiutak people left their Siberian home and their arrival in Alaska, Larsen and Rainey suggest that the Point Hope settlement dates back to the first or second centuries A. D. In view of its iron-age connections this would be the earliest possible date for Ipiutak. It is difficult to see how such a culture, stemming directly from the Siberian iron age,

could have played the highly important role ascribed to it in the formation of Eskimo culture, as described below. The question arises, however, whether it is necessary to postulate an actual migration of the Ipiutak people or their immediate ancestors from the Ob and Yenesei region in order to account for certain Siberian elements in their art, religion, and ceremonialism. The more normal process of culture diffusion would seem a better explanation.

On the basis of their description and analysis of the Ipiutak culture Larsen and Rainey (1948) have proposed a new theory of the origin and relationships of the various Eskimo groups. According to their view, Ipiutak represents the type culture of a Palae-Eskimo complex—the original foundation on which all other Eskimo cultures rest. The Ipiutak complex includes the closely related Near Ipiutak, inland groups such as the Nunatagmiut of northern Alaska and the Caribou Eskimos west of Hudson Bay, the prehistoric Dorset culture of the Eastern Arctic, the Kachemak Bay and Aleutian cultures of south Alaska, and the modern Eskimos on the Bering Sea coast south of Norton Sound. With the exception of the modern Bering Sea Eskimos, all these groups had in common an economy based primarily on caribou hunting, sealing, and fishing; they used implements of chipped stone more than rubbed slate, and they lacked knowledge of pottery, whale hunting with floats, and dog traction. These seven widely scattered Eskimo groups are placed in the "Ipiutak complex," which is equated with Birket-Smith's Palae-Eskimo stage.

Though Old Bering Sea is supposed to have been an outgrowth of Ipiutak, it is placed in a separate category, the "Arctic Whale Hunting culture," which also includes the prehistoric Punuk, Birnirk, and Thule cultures and the modern Eskimos of northern Alaska and Greenland. It corresponds to Birket-Smith's Neo-Eskimo stage. The Arctic Whale Hunting culture, according to this theory, is a later stage which, having sprung from Ipiutak, had an independent development on the islands around Bering Strait where caribou hunting was replaced by an economy centered on the hunting of sea mammals—seals, walrus, and whales. Correspondences between Ipiutak and the Whale Hunting cultures—which are many and close—are regarded as the result of contact; those between Ipiutak proper and other members of the Ipiutak complex, which are fewer in number and of a more general character, are considered evidence of genetic relationship.

In a theoretical structure as elaborate and inclusive as this there naturally are many debatable points, which need not be discussed here. It is possible to accept the Asiatic affiliations of the Ipiutak culture, its relationship with modern Bering Sea and prehistoric south Alaskan and Dorset cultures, and its possible, but not yet proved, association with inland Eskimo culture as represented by

the Nunatagmiut. At the same time one may question the reality of the proposed dichotomy in Eskimo culture, the dissociation of Ipiutak and Old Bering Sea, the view that Ipiutak is a transplanted Asiatic culture, and the assumption that Ipiutak, strongly influenced as it was by late bronze- and iron-age cultures of Eurasia, was older than and ancestral to all other known forms of Eskimo culture.

South Alaska.—When discovered by the Russians in the eighteenth century, south Alaska was one of the most densely populated sections of aboriginal North America. The Aleuts on the Aleutian Islands are estimated to have numbered between 15,000 and 25,000 and the Kodiak and Prince William Sound Eskimos about 10,000. The large number of old village sites in this area, especially in the Aleutians and on Kodiak, shows that the prehistoric population was equally great.

As the territory of these southernmost Eskimos and their linguistic relatives, the Aleuts, lay close to that of the Northwest Coast and interior Indians, they have, as might be expected, absorbed some elements of Indian culture. Their physical type, too, has been modified by Indian contact. However, the archeological evidence indicates that it is the modern culture of these regions that has been most strongly affected by such contact. The oldest stage of Kachemak Bay culture in Cook Inlet is definitely more Eskimolike than the later stages (de Laguna, 1934), and this seems to have been true also of Kodiak and the Aleutian Islands. We know from the hundreds of skeletons excavated by Hrdlička and Laughlin that the earliest inhabitants of Kodiak and the Aleutians were much closer in physical type to the Bering Sea Eskimo than are the modern Aleut and Koniagmiut (Hrdlička, 1944, 1945; Collins, 1945; Laughlin, 1950).

The relationship between the prehistoric cultures of south Alaska and Bering Strait is not yet clear. The south Alaskan culture as a whole can be described as generalized Eskimo, possessing many basic Eskimo features as well as others unknown in the north. Punuk art motifs occur in the late prehistoric deposits both at Cook Inlet and the Aleutians; and objects found in the lower levels of the Aleutian middens (pl. 1, g-i) are decorated in a style that suggests both Dorset and the earliest phase of Old Bering Sea art (Quimby, 1945; Collins, 1940). Also, certain types of harpoon heads, arrowheads, stone blades, and other objects indicate a relationship between the prehistoric Aleutian and Ipiutak cultures. The evidence at our disposal, both cultural and physical, indicates that south Alaska was a center of vigorous culture development around 2,000 years ago, that the basis of the culture established there was Eskimoan and that its carriers left the Bering Strait region before the Old Bering Sea and Ipiutak cultures were fully formed.

OLD WORLD RELATIONSHIPS OF ESKIMO CULTURE

The archeological discoveries sketched in the preceding pages have provided a wealth of new information on prehistoric Eskimo cultures in Alaska, the Central regions, and Greenland. If they have not brought complete disproof of the American-origin theory they at least have invested it with such serious difficulties that the theory must fall of its own weight. Since, according to this theory, the Proto-Eskimos are supposed to have lived as nomads in the Barren Grounds west of Hudson Bay, they could hardly have left archeological remains. However, as the culture of the Proto-Eskimos is supposed to have been essentially the same as that of the Caribou Eskimos, their modern descendents in the Barren Grounds, this type of culture or something like it should appear in the oldest archeological horizons. This expectation, however, is not realized. The oldest known Eskimo cultures, particularly those in Alaska, show no resemblance whatever to the supposed Central prototype.

It now appears extremely unlikely that there will be found anywhere in the American Arctic a simple proto-Eskimo or parent culture from which the various modern Eskimo cultures originally sprang. The oldest known Alaskan Eskimo cultures, instead of being simple, are already specialized and highly developed. As Bering Strait itself was an important culture center in prehistoric times the stages immediately antecedent to Ipiutak and Old Bering Sea will probably be found in the same region. Beyond this, however, we must look to the Old World. For if we postulate an origin for Eskimo culture anywhere in America we are faced immediately with the difficulty that the basic features of the oldest known Eskimo cultures are much more Asiatic, or Eurasiatic, than American.

Years ago, before archeological work had been undertaken in the Arctic, Thalbitzer, Hatt, and Kroeber, among others, presented weighty reasons for assuming that the basic substratum of Eskimo culture was Asiatic. The first systematic excavations—those made by Mathiassen at Thule culture sites west and north of Hudson Bay—brought tangible evidence sustaining and strengthening this point of view. The discovery of the Birnirk culture in Alaska, which was ancestral to the Thule, and of the related but still earlier Old Bering Sea culture, yielded a mass of new data which pointed conclusively in the same direction. Not one element of the Birnirk and Old Bering Sea cultures was exclusively or predominantly American in character. On the contrary, all of them were basically Asiatic. It is only in the Old World that we find either existing today or having existed in earlier times all the following elements: The square, wooden semisubterranean house with entrance passage, skin boats, sleds and toboggans, the toggle harpoon head, inserted side blades on imple-

ments, the throwing board and bird dart, lamps, pottery vessels, needle cases, and chipped-stone and rubbed-slate implements. These elements constitute the core of the Old Bering Sea and Birnirk cultures. Some of them—the square underground house, the throwing board, pottery, and chipped-stone implements—are also widely distributed in America but are equally widespread and of greater antiquity in Eurasia. The others are all deep-rooted elements of Old World culture that in America are found only among the Eskimos or in contiguous areas where Eskimo influence has probably extended. On the basis of the original Alaskan excavations, therefore, it seemed only reasonable to conclude that the roots of Eskimo culture were to be sought in Eurasia and not America.²

The discovery of the spectacular Ipiutak culture at Point Hope, Alaska, enables us to proceed beyond the demonstration of a general Eskimo-Old World relationship and to point to more specific connections.

One of the most striking features of the Ipiutak culture is the great number of chipped-stone implements, especially small, thin, lanceolate arrowpoints; rubbed-slate blades are entirely absent. The Ipiutak flint complex resembles those of the other early Eskimo cultures—Old Bering Sea, Kachemak Bay, Aleutian, and Dorset—in having an abundance of chipped-stone implements, whereas the later cultures all show a preponderance of rubbed-slate; likewise a number of specific Ipiutak types are shared with the cultures mentioned. Small, finely chipped arrowpoints like those from Ipiutak are also found in Eurasia. They have been described from old sites in Kamchatka and the Kurile Islands and are among the most characteristic features of a widespread Neolithic complex extending from Mongolia and the Baikal region to the Ural Mountains. The arrowpoints illustrated by Prokoshev (1940, pl. 3, figs. 9–14), from the Astrakhan site on Lake Griaznoe, near the confluence of the Chusov and Kama Rivers on the west slope of the Urals, are particularly close to the Ipiutak forms.

The excavations of the Russian archeologist A. P. Okladnikov have supplied what has long been needed, an analysis and description of the various stages of the Siberian Neolithic (Okladnikov, 1938, summarized by Collins, 1943). On the basis of excavation of graves and habitation sites on the Angara River and elsewhere around Lake Baikal, Okladnikov recognizes six culture stages preceding the iron age. The early inhabitants of the Baikal region are described as hunters, fishers, and food gatherers who lived in settlements along the lakes and rivers. Their mode of life represented a continuation from the upper Paleolithic of the same region, but the

² Gjessing (1944), approaching the problem from the opposite direction—the stone-age cultures of northern Eurasia—arrived at the same conclusion, quite independently and without knowledge of the Alaskan excavations or the conclusions that had been drawn therefrom.

environment in which they lived was essentially that of the present and the animals they hunted were all of species still living today. Okladnikov regards the Baikal Neolithic as the Siberian equivalent of the European Mesolithic and dates it from the sixth millennium to the tenth century B. C., an estimate which, however, may be somewhat excessive. It would probably be better, following Clark (1940), to regard the Lake Baikal remains as "modified" Mesolithic, for, unlike the European Mesolithic, they include Neolithic elements. The small, delicately chipped, symmetrical arrowpoints, closely resembling Eskimo and American Indian types, are unlike those from pre-Neolithic horizons in Eurasia. Likewise, at the Baikal sites there are neither microliths nor burins, implements that are characteristic of the European Mesolithic and that, like Mesolithic art motifs, represent a direct continuation from the Upper Paleolithic.

The three latest stages of the Baikal sequence included several distinctive types of artifacts and art motifs that were also characteristic of the Punuk, the intermediate stage of Alaskan Eskimo culture.

It is the earlier periods of Baikal culture—the Isakovski and Serovski—that are of particular interest and importance in connection with the problem of Eskimo culture. As might be expected, this early Neolithic was not a rich or elaborate culture. It is significant nevertheless that the entire range of implement types of the two oldest stages described by Okladnikov are, with the exception of shell beads and a few other ornaments, types which also occur in prehistoric Eskimo culture. These are the bow and arrow, polished-stone adzes, crescent-shaped jade and schist knives, scrapers, knives and lances with side blades, needles, needle cases, awls, and pottery vessels with conical and rounded bases.

Among the most striking features of the early Lake Baikal Neolithic are lances and knives with rows of small stone blades inserted in the edges (fig. 2, d). Side-bladed implements of corresponding form are also known from Neolithic Yang Shao sites in western China and Tibet (knives) and from Neolithic cave sites just east of the Urals (arrowheads and lances or knives, fig. 2, c). Side-bladed knives and projectile points are even more typical of the Mesolithic of northern Europe, being found at sites in southern Sweden, Denmark (fig. 2, a, b), northern Germany, Esthonia, and Belgium. In Alaska the prehistoric Eskimos of the Ipiutak, Old Bering Sea, and Birnirk periods used side-bladed knives and also equipped some of their harpoon heads with small stone side blades. The Ipiutak now furnishes a closer parallel in having bone and ivory arrowheads and lances with rows of small side blades directly comparable with the Siberian and Mesolithic forms (fig. 2, e, f). These side-bladed arrowheads and lances are complex in form and their distribution is significant, being

restricted to the European Mesolithic, the related Neolithic of central Asia, and the Ipiutak Eskimo culture in Alaska. They are, therefore, one of the features most strongly indicative of a basic relationship between the Eskimo and Mesolithic-Neolithic cultures of Eurasia.

Other European Mesolithic features resembling those of prehistoric Eskimo culture are pottery lamps (Mathiassen, 1935), steep-sided, conical-based cooking pots, and barbed bone fish and bird spears

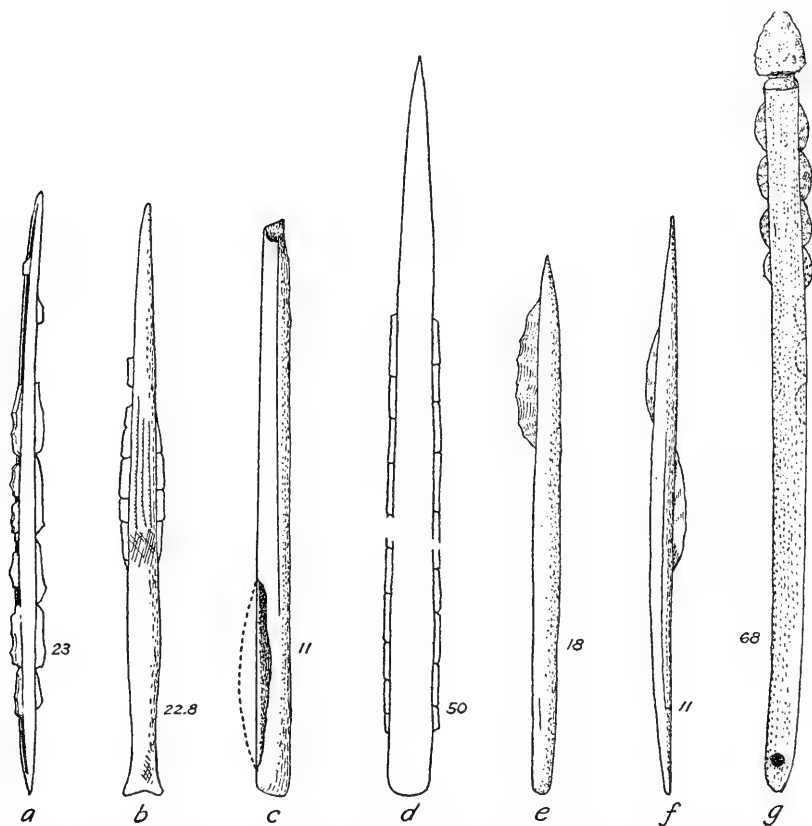
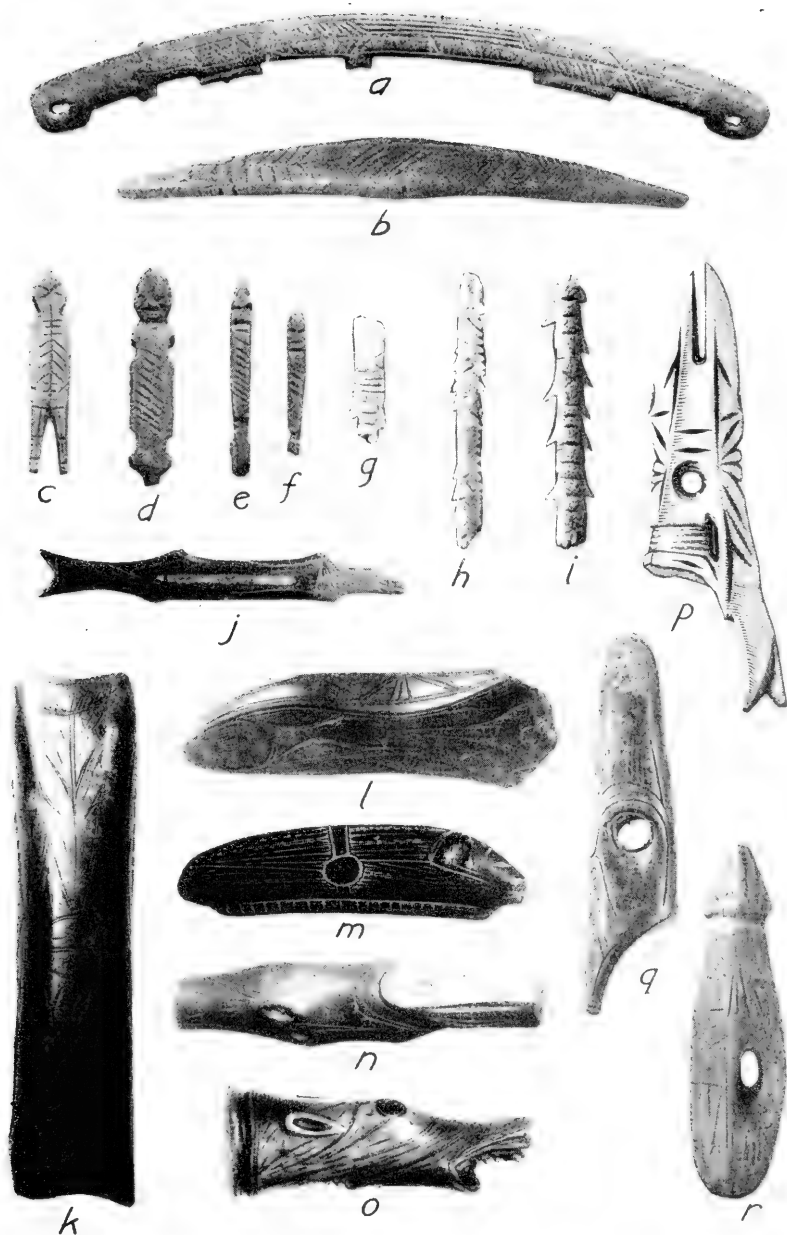
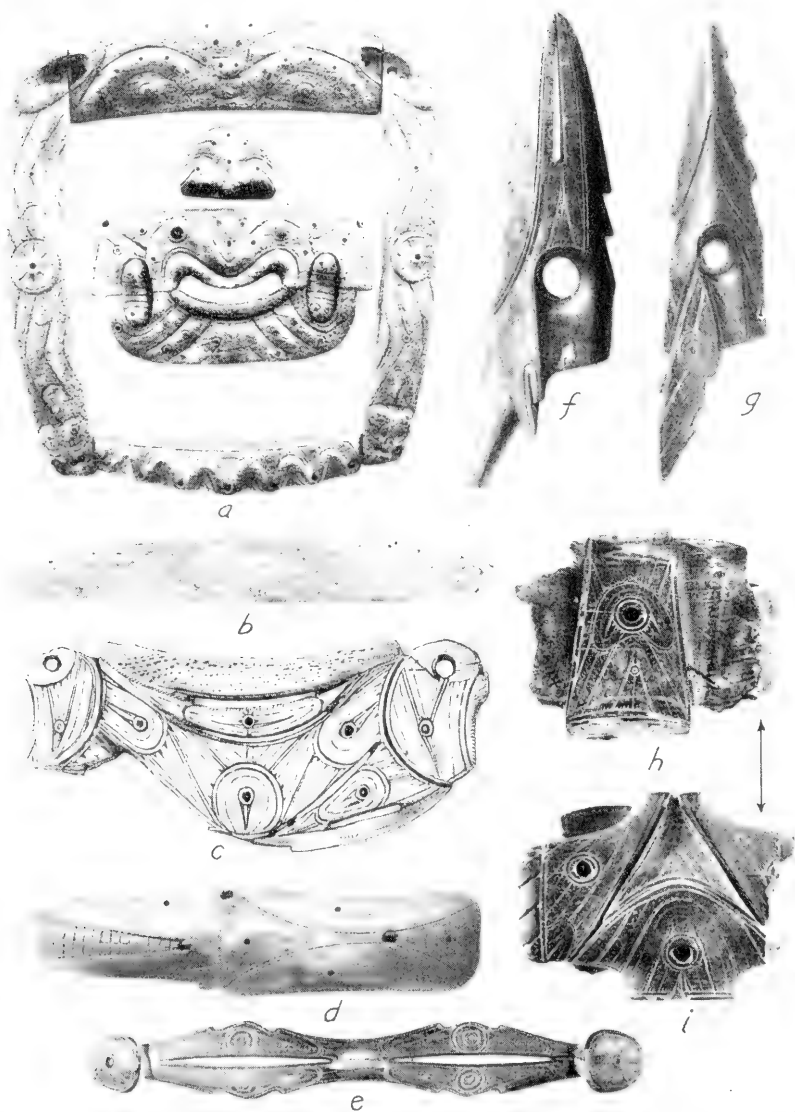


FIGURE 2.—Side-bladed implements—Mesolithic, Neolithic, and Eskimo. *a*, *b*, Denmark (after Madsen). *c*, Pechma River, District of Kamychlov, Perm (after Tolmachev). *d*, Ponomarevsk, Angara River, Siberia (after Okladnikov). *e*, *f*, Ipiutak, Point Hope, Alaska (after Rainey). *g*, Southampton Island, Hudson Bay (after Boas). (Not to scale; numbers indicate approximate length in centimeters.)

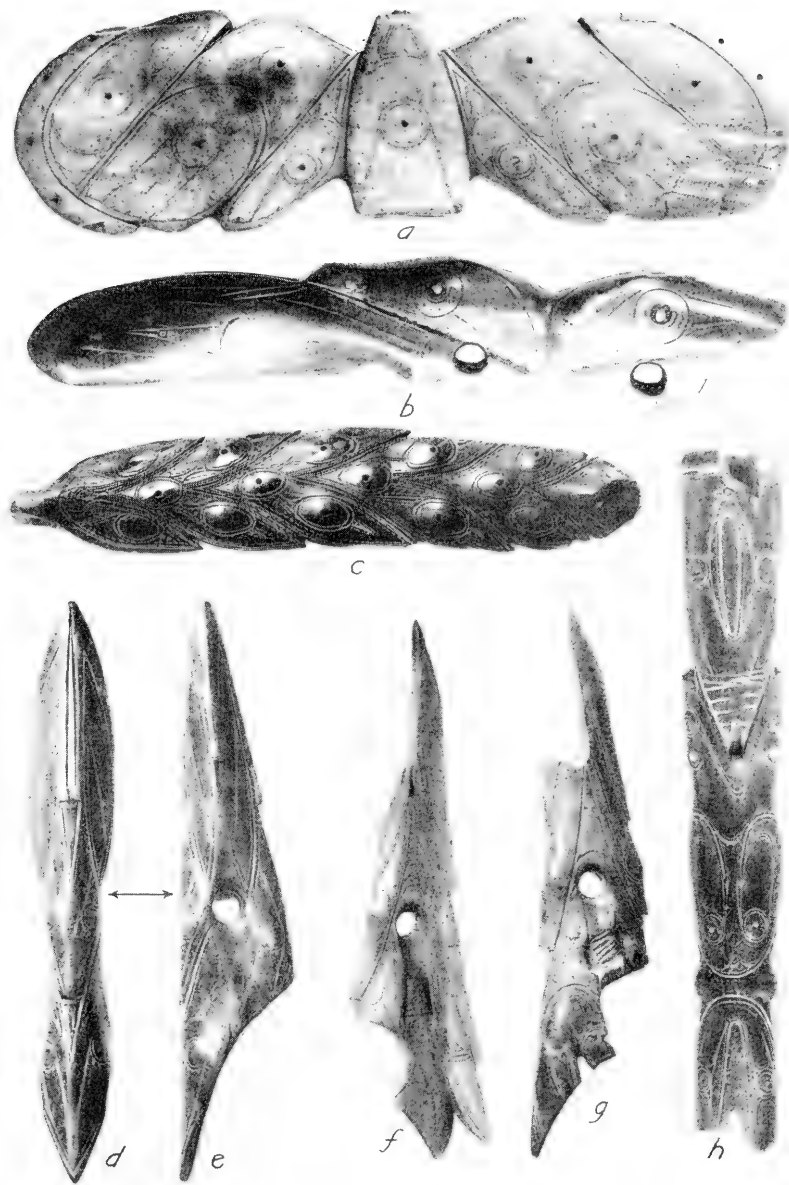
(Clark, 1936, fig. 41, pls. 6, 7). Finally, it should be noted that there seem to be significant resemblances between the geometric art of the European Paleolithic and Mesolithic and some of the simpler linear designs of Dorset and early Old Bering Sea art; some of the older Eskimo designs and motifs are actually closer to Paleolithic and Mesolithic art than to later styles in either America or Eurasia (de Laguna, 1932-33; Collins, 1940, 1943).



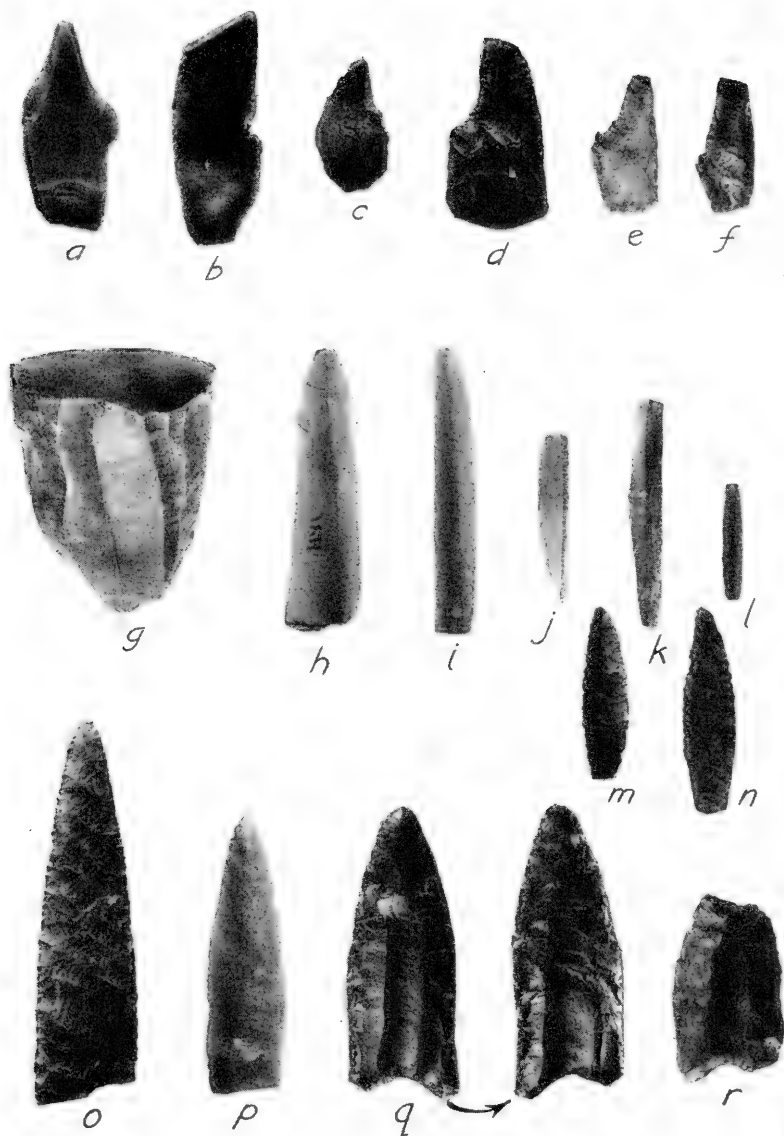
Early linear styles of Eskimo art from Greenland, Canada, and Alaska. *a*, Dorset quiver handle, antler, Northwest Greenland, 1:2, and *b-f*, wooden objects, Dorset, from Bylot Island, 1:3 (after Mathiassen). *g-i*, Bone dart points with Dorset-like designs, Aleutian Islands, 1:4 (after Quimby). *j-m*, Ivory objects decorated in Old Bering Sea style 1, Gambell, St. Lawrence Island, Alaska, 1:2. *n*, *p*, Ivory socket piece and harpoon head, Little Diomed Island, 2:3. *o*, Carved animal head from Okvik site, Punuk Island, same period as *j-n*, 1:2 (after Rainey). *q*, Antler harpoon head, Ipiutak, Point Hope, Alaska (after Larsen and Rainey). *r*, Ivory harpoon head of unusual type from base of midden, Punuk Island, 2:3.



Ivory objects decorated in Old Bering Sea style 2, Alaska. *a, b*, Masklike carvings and ornamental band, Ipiutak (after Larsen and Rainey). *c*, Gorget, and *d*, plaque, Gambell, St. Lawrence Island, 2:3. *e* and *g*, Pail handle and harpoon head, northern Alaska, 1:2. *f*, Harpoon head, Little Diomed Island, 1:2. *h, i*, Center of ivory winged object like plate 3, *a*, northern Alaska, 1:2.



Ivory objects decorated in Old Bering Sea style 3, Alaska. *a*, Winged object, use unknown, Point Hope, 1:2. *b*, Object of unknown use, northern Alaska, 2:3. *c*, Box or pail handle, and *f*, *g*, harpoon heads, Gambell, St. Lawrence Island, approx. 1:2. *d*, *e*, Harpoon head, northern Alaska, approx. 1:2. *h*, harpoon socket piece, Kukulik, St. Lawrence Island, 2:3.



Stone implements from early pre-Eskimo sites in Alaska. *a-d*, Flint burins, Cape Denbigh, Norton Sound, 3:5 (after Giddings). *e-f*, Flint burins, and *n*, flaked blade, Anaktuvuk Pass, Brooks Range, 2:3 (after Solecki). *g*, Flint core, and *j-l*, lamellar flakes, Anaktuvuk Pass, 2:3 (after Solecki). *h, i*, Lamellar flakes, and *m, o, p*, flaked blades, Cape Denbigh, 3:5 (after Giddings). *q*, Fluted blade, Folsom type, Utukok River, Northwest Alaska, 3:5 (after Thompson). *r*, Fluted blade, Kugururok River, tributary of Noatak, Northwest Alaska, 3:5 (after Solecki).

Further information will be needed, particularly on the archeology of the vast region between Lake Baikal and the Pacific and Arctic Oceans, before the postulated Siberian-Eskimo relationships can be fully understood. Okladnikov's investigations alone, however, sustain to a remarkable degree Hatt's view of the origin of Eskimo culture and of the development of culture generally in northern Eurasia and America. Hatt's theory, which was based originally on an exhaustive study of clothing types, postulated the existence of two great culture waves or strata in northern Eurasia and America. The older stratum, which Hatt called the "coast culture," originally occupied the inland waterways and later the coasts of northern Eurasia. Spreading eastward it established itself on the Bering Sea and Arctic coasts of America where it developed into the Eskimo culture as known today. The younger wave or stratum, called the "inland culture," was most typically represented by such peoples as the nomadic Tungusians of central Asia, whose possession of the snowshoe enabled them to expand over the vast inland plains and woodlands.

Okladnikov's excavations in the Baikal region afford tangible evidence of a cultural development very much as envisaged by Hatt—an early population of hunters and fishers who lived a settled life along the lakes and rivers before these territories were taken over by the reindeer-breeding nomads. And, as we have seen, the material equipment of these early Neolithic peoples was basically similar to that of the oldest Eskimos in Alaska.

The role of the Lake Baikal Neolithic in the formation of Eskimo culture has been emphasized because this is the particular Neolithic setting for which sequential stages have been most fully revealed and in which Eskimo affinities are most apparent. There were, of course, other Neolithic centers in the inland zones of Eurasia that may have contributed to the development of the coast cultures from which Eskimo culture sprang. Neolithic sites are known from one end of Siberia to the other, and some of them, for example, cave sites on the east slope of the Ural Mountains (Tolmachev, 1913), have yielded culture remains closely resembling those of the Baikal region.

The exact nature of the relationship between the European Mesolithic and the early Siberian Neolithic is yet to be determined. It will depend in part upon another uncertain factor—the role of the Siberian Paleolithic in the formation of later stages of culture in Eurasia. The Upper Paleolithic cultures of central Asia differed in many respects from those of western Europe, and their influences appear to have extended even to the oldest cultures of Scandinavia (Gjessing, 1944). However, we need not be concerned here with the nature of the relationship or the direction of culture flow between the European and Siberian Paleolithic, the Mesolithic of northern

Europe, and the Lake Baikal Neolithic. Important as these questions are, they are not within the scope of the present paper which is concerned only with cultural analogies of immediate and demonstrable significance in connection with Eskimo origins.

If our interpretation of the evidence is correct, the Eskimos become the first American people whose cultural origins, on the basis of actual archeological comparisons, can be traced to a specific time and place in the Old World. The postulated place of origin is thousands of miles to the west of the present Eskimo territory, and the time thousands of years in the past. How is this to be reconciled with the generally accepted view that the Eskimos were among the last of the Asiatic peoples to enter the American Continent, and particularly with the fact that the Eskimo culture exhibiting the closest Mesolithic-Neolithic affinities—the Ipiutak—had already been strongly influenced by late iron-age cultures of Siberia? Whether the theory that the Eskimos were late comers is still tenable in the light of recent archeological discoveries is something we will discuss later. However, assuming that it is, we would have a reasonable explanation of the seeming paradox in the phenomena of culture lag and culture stability in a marginal area. The taiga and tundra zones of central and northern Siberia formed a refuge area where basic culture patterns changed very slowly and at any given time in the past stood at an earlier stage of development than in adjacent regions to the south. In the relative isolation of the Arctic small groups of hunters and fishers who had moved north in Mesolithic-Neolithic times, and who later came to feel the impact of iron-age culture, perpetuated a basic pattern of life that had long since disappeared in the south. Thus there would be no real anachronism involved in the assumption that the oldest known Eskimos in Alaska and their immediate ancestors in northern Eurasia had continued a Mesolithic-Neolithic way of life, particularly in their subsistence activities and techniques, even though they lived in iron-age times and had absorbed features of iron-age culture.

PHYSICAL ANTHROPOLOGY

Anthropologists and anatomists by the score have speculated on the problem of Eskimo origins and have expressed widely differing opinions, none of which has provided a satisfactory answer as to when and where the Eskimo race type arose. Even today, with the wealth of new information we have on the development of Eskimo culture, we are still unable to speak with assurance on the origin and affinities of the Eskimo race. The physical type associated with one of the oldest Eskimo cultures, the Dorset, is unknown, and the skeletons found at Ipiutak are still undescribed. We are likewise handicapped

by lack of full information on the physical type of the prehistoric Siberian peoples around Lake Baikal who, on the basis of culture, appear to have been in part, at least, ancestral to the Eskimo.

On the other hand, we do have skeletal material from prehistoric Birnirk, Thule, Punuk, and Old Bering Sea sites, and there are clues of possible significance in Eurasia, to which we will refer later. Though the present evidence affords no conclusive answer to the problem of the Eskimo race type, we have at any rate advanced beyond the point where theories have to be erected on the basis of small series of measurements on the living or on collections of undated skeletal material.

In its most characteristic form the Eskimo skull exhibits a combination of features that makes it one of the most distinctive and easily recognized of all human types. The vault is extremely long, narrow, and high, with a ridgelike elevation—the sagittal crest—extending along the top from front to back. The forehead is somewhat narrow and sloping, and there is a marked protuberance of the occipital region. The face is high and broad, and, what is most unusual, broader than the skull itself. The cheek bones are very prominent and the orbits are high. In contrast to the massiveness of the face as a whole, the nose is extremely narrow and the brow ridges only slightly developed. The nasal depression is shallow and the nasal bones are very narrow, usually having a “pinched-up” appearance. The Eskimo jaw is large and heavy, the upper part, or ascending ramus, being very wide and having an outward flare at the back which gives the face its characteristic squarish shape. Another distinguishing feature of the Eskimo skull is the unusual thickness of the tympanic plate, the bony ledge bordering the ear opening. Bony swellings or overgrowths on the lower and upper jaws and palate, known respectively as mandibular, maxillary, and palatine tori, also occur more frequently among the Eskimo than any other people. It is suggested here that these features, which are especially characteristic of the Eskimo—the “pinched-up” nasal bones, thickened tympanic plate, and mandibular and palatine tori—may be of equal if not greater significance genetically than purely metrical features such as head length, head breadth, etc.

The specialized type of skull just described—long, narrow, high—is not universal among the Eskimos, though it predominates in parts of West and East Greenland, the Mackenzie Delta, and in parts of northern Alaska. We know that the type is one of considerable antiquity because the skulls from the old Birnirk sites around Point Barrow already exhibit it. Of the three Old Bering Sea skulls that have been found, two conform to this type, while the third is meso-cranic, or of medium length.

Skeletal remains of the modern Hudson Bay tribes are lacking but Birket-Smith's (1940) measurements show that the present-day Caribou, Netsilik, and Iglulik Eskimos are closer to the Cree and Chipewyan Indians than to other Eskimos. This resemblance is borne out visually, for the photographs of most of these Central Eskimos definitely suggest Indian, or in some cases European, mixture.

The Alaskan Eskimos in general are taller and more broad-headed than most of their eastern kinsmen. This has usually been attributed to Indian mixture. Unquestionably there has been ample opportunity in Alaska for this to have occurred, especially along the rivers where the Eskimos come into direct contact with the interior Athapaskans. Seltzer's analysis of Stefansson's measurements showed that the Nunatagmiut, an inland Eskimo group living along the Colville River in north Alaska, differ sharply from other Eskimos and conform more to the Indian type (Seltzer, 1933). In the same way, the Eskimos on the Kobuk and other northern rivers, and occasionally even some of those in the coastal settlements of northern Alaska, are much more Indian in appearance than Eskimo; this is also true of some of the Kuskokwim and Yukon Eskimos.

Elsewhere in Alaska, Eskimo-Indian admixture is much less apparent, and it is questionable whether the physical type of the other Alaskan Eskimo groups has been seriously affected by Indian contact, at least in recent centuries. The modern Eskimos along the coast from Barrow to Bering Strait are of the generalized northern Eskimo type. Though they do not exhibit the hyper-Eskimo features of the old Birnirk population they are still Eskimo in every respect, being practically identical with the old Thule type of the central Arctic (Fischer-Møller, 1937). At Bering Strait and a few other places on Seward Peninsula the long-headed Birnirk type has survived to the present time. The Alaskan Eskimos south of Seward Peninsula differ from those to the north in having shorter, broader, and lower heads, broader faces and noses. They resemble rather closely Hrdlička's "pre-Koniag," the early oblong-headed type from Kodiak Island, which, on the basis of archeological data, may have an antiquity of around 2,000 years.

The problem is to account for the origin of the two oldest Eskimo types of which we have knowledge, the highly specialized, extremely long-headed northern type, represented by the Birnirk crania, and the more generalized, but equally ancient oblong-headed type of south Alaska.

Before proceeding further we may digress to mention here one explanation that has been advanced repeatedly and that would solve the problem very simply by asserting that the most pronounced features of the Eskimo skull are the result of functional adaptation. The muscles of mastication, powerfully developed through chewing

of tough food, are supposed to have compressed the skull laterally, thereby producing the long, narrow, keel-shaped vault so characteristic of the race. The same explanation is often advanced to account for the presence of mandibular and palatine tori—the bony swellings frequently found on the lower jaw and palate—as well as the strongly developed jaws, excellent teeth, and massiveness of the face in general. There are, however, serious objections to the “hard-chewing” hypothesis that its advocates do not take into account. In the first place, one may question the necessity of calling in a specific and functional explanation of the Eskimos’ dolichocephaly when there are many other long-headed races, such as the prehistoric Texas cave dwellers, the Perique of Lower California, the Veddas of Ceylon, and various European and African peoples whose skull form is obviously not to be explained on this basis, since their faces and jaws, which would be the parts most directly affected by vigorous chewing, are for the most part rather small and weakly developed. Also, if skull form and facial development both resulted from hard chewing, why should some Eskimos have large faces and long heads and others large faces and broad heads?

Stefansson, who has lived for long periods among the Eskimos and who can speak with authority on their dietary habits, contends that there is no factual basis for the belief that they chew more vigorously than other people. He points out that boiled meat, which is the Eskimo’s first preference, requires very little chewing, that raw meat is usually not chewed but gulped down like an oyster, and that frozen fish, when sufficiently thawed to be edible, is about the consistency of hard ice cream (Stefansson, 1946). The only really tough food eaten by the Eskimos is dried fish and meat, but the use of such food is by no means universal, for there are many districts where it is seldom eaten.

There are two specific facts that alone are enough to invalidate the theory that the typical long and narrow skull of the Eskimo is an adaptation resulting from vigorous use of the masticatory muscles: (1) The Eskimos who consume the greatest quantities of really tough food—dried fish and meat—are those living in Alaska, especially to the south of Bering Strait. Yet the skulls of these Alaskan Eskimos are not long and narrow but relatively short and very wide, in fact wider by a considerable margin than those of any other Eskimo group. (2) If the assumed lengthening of the head were a functional and progressive condition we should expect the most ancient crania to be at least somewhat shorter and wider than the modern. However, exactly the reverse is true, for as already pointed out the oldest skulls from northern Alaska are of the extremely long, high, narrow type. Similarly, the modern broad-headed Aleuts and Kodiak Islanders were preceded by earlier oval-headed populations. In view of this

actual succession of cranial types, the functional theory falls completely to the ground, for if applied here it would mean that 2,000 years of hard chewing had produced not a long and narrow but a broader and more rounded form of skull.

Similar difficulties are encountered in attempting to explain the broad and massive face of the Eskimo as a progressive response to the energetic use of the jaws, for the old Birnirk Eskimos and the early population in the Aleutian Islands already exhibit facial diameters comparable in general to those of other Eskimo groups. The Mongols from Urga have facial measurements almost identical with Birnirk and show an accentuated development of the malar and upper maxillary regions comparable in every way to that of the Eskimo. Since the Mongols' diet of milk and cheese is not one requiring excessive use of the jaws, the functional theory cannot be adduced to explain their large and heavy faces. The total evidence, therefore, sustains the views of Hooton, Jenness, and Birket-Smith that the Eskimos have inherited and not acquired their peculiar skull form.

We may inquire, then, whether it is possible to identify the ancestral type, either in America or Asia. A number of attempts have been made to establish relationships between various Indian and Eskimo groups on the basis of either skeletal material or measurements on the living. Though we need not subject these claims to detailed scrutiny, it will be pertinent to review them briefly to see if they meet certain minimum requirements. For example, when physical resemblances between living Indians and Eskimos are interpreted as evidence of a basic relationship we need to know first whether the resemblances in question could be due to recent intermixture between the two groups; and second, whether the groups compared are representative of the original populations.

The latter consideration brings up the highly important question of white mixture, something too frequently ignored by anthropologists who have concerned themselves with the problem of the racial origin of the Eskimo. In parts of Labrador and West Greenland the infiltration of European blood has been going on for some 200 years, not to mention the probability of still earlier Norse mixture. In southern Alaska, particularly in the Aleutian Islands, the process of miscegenation began with the arrival of the Russian fur hunters in the middle of the eighteenth century. In northern Alaska the process was delayed for another hundred years, when the whaling fleets appeared in Bering Sea and the Arctic. Today, white mixture is apparent in many of the Eskimos of the Bristol Bay-Kuskokwim region, mainly the result of Russian contacts, and individuals of mixed Eskimo and white ancestry comprise an appreciable minority among the more northerly Eskimos. On the Diomed Islands, for example, most of the children and a considerable number of adults

show clear evidence of white admixture, and to a lesser extent this is also true of nearby Wales. Here, and elsewhere on Seward Peninsula, the greatest dilution of Eskimo blood has occurred since 1900, beginning with the influx of miners and other whites during the Gold Rush. In view of these conditions it is obvious that extreme caution must be observed if anthropometric data on the living are to serve as a basis for discussion of racial affinities and origins. Skeletal material that antedates the period of white contact is far more reliable for such a purpose. In this case the principal requirement is that the total evidence, metrical and morphological, be presented, and not merely a few selected measurements.

The most extensive body of anthropometric data on the Eskimos of North Alaska and Coronation Gulf is that obtained by Vilhjalmur Stefansson who between the years of 1906 and 1912 measured 526 adult Eskimos from Kotzebue Sound eastward to Coronation Gulf. Particularly valuable are Stefansson's measurements of 127 Nunatagmiut, the inland Eskimos of the Colville River region, who are now virtually extinct. Seltzer, who made a careful study of Stefansson's data, showed that the Nunatagmiut and Mackenzie Eskimos differed sharply from all other Eskimos. The Nunatagmiut, with their broad short heads, short trunks, and long legs, were more Indian than Eskimo in physical type. According to Seltzer these Eskimos must have absorbed considerable Indian blood in comparatively recent times, which would not be surprising in view of their interior location in proximity to the Alaskan Athapaskans. The Mackenzie Eskimos, on the other hand, represented the opposite extreme, with very long and narrow heads, long trunks and short legs—features which marked them as the most Eskimoid of all the groups. From this Seltzer concludes that the Mackenzie Eskimos are the direct descendants of the old Point Barrow (Birnirk) population, a deduction which seems soundly based.

After demonstrating the interrelationships of the various Eskimo groups measured by Stefansson, Seltzer attempts to show that one segment of the Eskimo population, including the Caribou Eskimo on Hudson Bay, the Labrador and East Greenland Eskimo, were descended from the Cree Indians; another major grouping, including the Copper Eskimos of Coronation Gulf and the Kotzebue Sound, Seward Peninsula, and St. Lawrence Island Eskimos were the descendants of the Chipewyan Indians of the Lake Athabaska region.

Seltzer's first grouping is of particular interest because there undoubtedly does exist a prominent Indian strain among the Canadian Eskimos. Numerous observers have recognized this, and without recourse to measurements; the facial features of many of the Canadian Eskimos are distinctly "Indian" rather than Eskimo. Steensby, for example, was aware of this when he pointed out that among the Polar

Eskimos of northwest Greenland the descendants of an immigrant Canadian group from Pond's Inlet differed from the other Polar Eskimos in having distinctly Indian features. In 1948 the present writer had an opportunity to take measurements and observations on 80 adult Nugumiut Eskimas at Frobisher Bay on Baffin Island. Two basic, contrasting types were discernible among these Eskimos, even though a number of the individuals were blends between the two and others exhibited white mixture. The majority type exhibited the somewhat bland "Oriental" features usually associated with Eskimo—light skin color, very broad, round to squarish face, high cheek bones, small flat nose, low, narrow forehead, slightly oblique eyes and epicanthic fold. In the minority, or "Indian" type, the head is slightly longer, the face is more bony and rugged and somewhat longer and narrower, with the cheekbones standing out prominently because of relative lack of fat in the cheeks; the eyes are horizontal and usually lack the epicanthic fold; skin color is darker, the nose longer and more convex, and the mouth larger.

It is tempting to speculate on the possibility that these two physical types may be representative of the two prehistoric Eskimo groups of southern Baffin Island—the Dorset and Thule. As no skeletal remains have been found at Dorset sites the physical type associated with this early culture of the eastern Arctic is unknown. In the absence of direct evidence, it is possible that Dorset art might throw some light on the problem. In their bone carvings the Dorset artists portrayed two distinctly different types of human faces, placed side by side on the same piece of bone or antler (see Rowley, 1940, fig. 1, a; another carving much like this from Boothia Peninsula collected by Learmouth, now in the Royal Ontario Museum, and two somewhat similar specimens, also possibly Dorset, from the Egedesminde and Ammassalik districts in Greenland). The first type of face is broad and round in shape with oblique eyes and short, wide nose—what might be described as a caricature of the typical "Eskimo" face. The other type shows a long, narrow face with long nose. It is less stereotyped in appearance and might conceivably represent either Indian or European (Norse?). Assuming them to represent two distinct aboriginal types, one would guess that the first would be Thule and the second Dorset. It would be better, however, to defer speculation on such questions and await more definite evidence. It will be sufficient for our present purpose to confirm the existence of these two physical types, the Indian like and the Eskimo, among the central Eskimo population.

With regard to Seltzer's theory of the Indian (Cree) origin of the Caribou, Labrador, and Ammassalik Eskimos, we may pose two questions: Are these three Eskimo groups so similar in physical type

that they may be assumed to have had a common ancestry? And, are the hypothetical ancestors pure-blood Indians?

As to the first question, the answer seems to be affirmative, as far as the measurements themselves are concerned. The three groups are very much alike in stature, length and breadth of head, and length and breadth of face. It is quite evident, however, that two of these groups—the Caribou and Labrador Eskimos—are by no means pure Eskimo. Stewart (1939) has demonstrated this for the Labrador group, and Birket-Smith's photographs leave no doubt of the considerable amount of white blood present among the Caribou Eskimos. The Ammassalik people, on the other hand, show no such evidence of white mixture. If we may judge from the photographs published by Thalbitzer, Holm, and others, the Ammassalik are one of the purest of all Eskimo groups, showing not the slightest resemblance to the Cree or any other Indians. This is one of those instances, not uncommon in anthropology, where metrical comparisons alone are misleading.

As to the second question, it appears that the Cree Indians at Fort Chipewyan on Lake Athabaska who were measured by Grant (1930) and who, according to Seltzer, represent the type ancestral to the Caribou, Labrador, and Ammassalik Eskimos, are by no means full-bloods. Grant showed that this group of Crees were practically identical, except in stature, with a group he had measured earlier at Oxford House. The latter were clearly mixed-bloods, as they themselves recognized. They were very close metrically to mixed-blood Sioux, from which Grant (1929, p. 27) concludes: "We surmise that the Oxford House Indians have likely as great an admixture of white blood as have the half-blood Sioux." Considering that the Indians in this part of Canada have lived in contact with whites for many years (Fort Chipewyan was established in 1789 and Oxford House in 1792), it is inevitable that extensive race mixture should have occurred. As the modern mixed-blood Cree do not represent the original physical type of the group it is obvious that their measurements cannot be used to trace original relationships. Stewart, in commenting on this same suggested relationship between Eskimo and Cree, has expressed a similar opinion: "I object chiefly to drawing such far-reaching conclusions from such unequal material . . . in other words, to concluding from the similarity of a few measurements taken on small samples of widely separated modern groups, speaking different languages (Eskimo, Algonkian Cree) and undergoing different stages of acculturation (Whites), that they must have had a common ancestry a little over 1,000 years ago" (Stewart, 1939, p. 120).

Birket-Smith remarks on the great physiognomic likeness between the Caribou Eskimos and Chipewyans he had seen on Churchill River,

and believes that the similarity in measurements between Hudson Bay Eskimo and Chipewyan-Cree sustains his view of the Indian origin of the Eskimo:

It is undeniable that the similarities between the [Hudson Bay] Eskimos and both the Cree and Chipewyan are remarkably great . . . all that can be said at present regarding the relationship between the Eskimos and the Northern Woodlands Indians is that in the regions about Lake Athabaska lives an Indian group whose likeness to the Eskimos seems unmistakable. This, however, is a fact of far-reaching importance. It agrees exactly with the opinion I advanced years ago, that the ancestors of the Eskimos once lived in the northern woodlands west of Hudson Bay. [Birket-Smith, 1940, p. 109.]

As indicated earlier, the archeological evidence lends no support to this theory. And the physical resemblances between Caribou Eskimo and neighboring Indians can support it only if one disregards the far more likely explanation that the resemblances in question are due to fairly recent contacts. Birket-Smith (1929, vol. 2, p. 41) has shown that while the Caribou Eskimos have been in contact with the Chipewyan for little more than 200 years, there had been an earlier period of contact with the Cree, as a result of which a number of Indian elements had been adopted by the Caribou. If there was cultural borrowing from these relatively recent contacts it would seem reasonable to suppose that there would also have been opportunity for race mixture.

Seltzer's other thesis—that the Copper Eskimos of Coronation Gulf and the Alaskan Eskimos of Kotzebue Sound, Seward Peninsula, St. Lawrence Island, and Southwest Alaska were descended from the Chipewyan Indians—was a reaffirmation of a similar theory originally proposed by Shapiro. From metrical resemblances between the Chipewyans and the Seward Peninsula, Coronation Gulf, and Smith Sound Eskimos, Shapiro concluded that the origin of these three Eskimo groups was to be found in interior Canada west of Hudson Bay:

Most probably these present Eskimo groups are derived from an Indian stock which migrated northward to the coast and then moved northeastward to Smith Sound and westward to Seward Peninsula. Finally, this migration seems to be recent and superimposed upon an earlier distribution of Eskimo. [Shapiro, 1931, p. 381.]

Here, as in the case of the Cree, we may first inquire as to the purity of the 44 Chipewyan Indians who, according to Seltzer and Shapiro, represent the ancestral stock from which these several Eskimo groups were derived. Grant, who measured the Chipewyans, was under no illusion as to their purity. He states specifically that the individuals in this group, who had been selected on the word of his Indian interpreters, were, on the basis of his own observations and measurements, no purer than the population as a whole:

... concerning the 44, assumed to be pure Chipewyan, it seems probable, now that the report is worked up, that the judgments of the interpreters have proved fallible, for it seems doubtful if the 44 men they selected as pure, are any more pure than the 33 men of the Fond-du-lac band who were induced to be measured, and who were taken at random. . . .

It becomes evident from a consideration of their general characteristics, teeth, blood, and physical proportions, that those "assumed to be pure" are actually slightly more mixed than the Fond-du-lac band as a whole. [Grant, 1930, pp. 7, 29.]

The correctness of Grant's judgment is borne out by his photographs, which show that half of the adults, from both Fond-du-lac and Chipewyan, are clearly mixed-bloods. As such they can hardly have played the ancestral role ascribed to them.

Leaving in abeyance the question of when and how the Indian strain entered the Central Eskimos, we may consider whether there is any validity in the idea that some of the Alaskan groups are of Indian origin. As mentioned before, it is not uncommon to find Eskimos with Indian-like features around Kotzebue Sound and elsewhere on the Arctic coast of Alaska. Such individuals, however, from this very fact stand out from the others. The simplest and most logical explanation is that a certain amount of Indian blood has been absorbed by the north Alaskan Eskimos in fairly recent times, an inevitable consequence of the fact that some Eskimo groups live far up the rivers in close proximity to the interior Athapaskans, and, further, that it was a general practice for the coast people themselves to roam far into the interior in pursuit of caribou. This, however, is very different from saying that these Eskimos as a whole are derived from an Indian stock. And we must certainly reject the idea that the Kotzebue Eskimos, most of whom are typically Eskimo in appearance, are of Indian descent because they show certain metrical resemblances to a mixed Indian-White group of Chipewyans living on Lake Athabaska far in the interior of Canada.

We come to the same conclusion when we examine the suggested relationship between Chipewyan and the St. Lawrence Island and Seward Peninsula Eskimos. We know from the archeological record that the relationships of the St. Lawrence Eskimos have always been with Siberia, only 40 miles away, and never with the Alaskan mainland. The archeological picture is one of the steady growth and development of an Eskimo culture, enriched from time to time by elements received from Siberia. Archeologically there is not the slightest trace of Indian intrusion. The physical evidence is equally decisive. The Old Bering Sea Eskimo on St. Lawrence Island, to judge from the few skulls that have been found, belonged to the highly specialized long-headed Birnirk type. The Punuk and modern St. Lawrence Eskimos are broader- and lower-headed, being practically identical with the Chuckchee, as Hrdlička has shown.

There are likewise no indications of an Indian irruption at Bering Strait. Skeletal material from a number of late prehistoric and recent sites on the south and west coasts of Seward Peninsula shows that the old long-headed Eskimo type has persisted there into modern times. This is true even at Wales where measurements on the living, taken by Weyer in 1928, revealed the supposed affinity with the Chipe-wyans. Many of the Wales people, however, are mixed-bloods, as the present writer knows from personal observation and as Weyer's photographs, published by Shapiro, also clearly show.

The principal reasons for the physical differences between the modern Eskimos of northern Alaska and their early Birnirk-type ancestors may safely be stated as (1) white mixture, (2) population movements within the Eskimo territory, such as the late return movement of Thule Eskimos from Canada to northern Alaska, and the migration of broad-headed Siberian Eskimos of Chukchee type to St. Lawrence Island beginning in Punuk times, and (3) at some places a certain amount of Indian blood that has been absorbed as a result of direct or indirect contacts between the Eskimos and the Alaskan Athapaskans. On the other hand, there is no evidence whatever of a mass movement or even infiltration of Indians from the interior to the Arctic or Bering Sea coasts at any time in the past.

Comparisons of Eskimo and Indian skeletal material have led to still other theories. Shapiro (1934) demonstrated a close metrical resemblance between the Huron Indians of southern Ontario and the Point Barrow, Seward Peninsula, and Nunivak Eskimos, which he felt indicated a common origin for these groups. Hrdlička concluded from his study of the "Pre-Koniags" that these earliest inhabitants of Kodiak Island were "physically related slightly to the Eskimo, but much more so to the Algonkian" (1944, p. 434). The lower-headed "Pre-Aleuts" from the Aleutian Islands, on the other hand, bore a close resemblance to the Sioux: "The characteristics of the pre-Aleut and Sioux skulls are seen to be so close that the anthropologist would seem justified in assuming that the two groups had a common and not very far back ancestry" (Hrdlička, 1945, p. 583). However, the striking differences between Pre-Aleut and Sioux long bones, both in size and proportions, created a doubt as to their common ancestry (1945, p. 584).

What is the significance of the very close metrical resemblance between these widely separated peoples? First, we may question the view that the Pre-Koniag are more closely related to Algonkian than to Eskimo. Hrdlička showed that the Pre-Koniag were very different from Eskimos when compared with a pooled series of the Eskimo in general, including those from Greenland and Labrador. However, if the Pre-Koniag are compared with the Eskimo groups nearest to them geographically—those along the Bering Sea coast north to

Norton Sound—a much closer resemblance appears; they are much closer both in measurements and indices to these other Alaskan Eskimos than to the Algonkians (Collins, 1945). Similarly, though in cranial and facial measurements the Pre-Aleut are very close to the Sioux Indians, there are sufficient resemblances to the Bering Sea Eskimos to cast doubt on Hrdlička's statement (1945, p. 579) that the Pre-Aleut "were definitely not Eskimo, nor even their very close relations." It must be remembered that the modern Aleuts spoke a divergent Eskimo dialect and possessed a culture that was basically Eskimo, while the Koniag were actually Eskimos, both linguistically and culturally; the fact that these two modern groups differed physically from the highly specialized long-headed Eskimo type of north Alaska and Greenland is merely indicative of the great physical diversity that exists within the Eskimo stock. The Pre-Koniag and Pre-Aleut, with their longer, narrower, and higher heads and faces, were more Eskimoid than their successors, thereby indicating that in earlier times there was a greater degree of physical unity among the Eskimo than at present.

Despite the fact that the Pre-Aleut were more Eskimoid than the later Aleuts, their remarkably close metrical resemblance to the Sioux must be recognized, even if it cannot be explained, and the same is true for the close similarity between the Seward-Barrow Eskimos and Huron Indians pointed out by Shapiro. In the measurements used for comparison the Hurons are actually closer to the far-away Point Barrow Eskimos (average difference only 0.99 mm.) than they are to their Iroquoian kinsmen in New York or to the neighboring Algonkian Indians of New York, Massachusetts, and Maine (average difference of 1.89 mm.). No one would think of suggesting that the Huron Indians for this reason were more closely related genetically to Point Barrow Eskimos than to other Iroquois. That the measurements themselves point to such an anomalous result is sufficient reason for questioning the validity of this method of comparison. The explanation, I suggest, is that the comparisons are not complete. If, instead of comparing tables of measurements, an anthropologist had before him the actual skulls, he would have no difficulty in distinguishing between Eskimos and Hurons, Pre-Koniag and Algonkians, and Pre-Aleuts and Sioux. Each paired series would differ markedly in such morphological features as contour of the skull, size and shape of the nasal bones, slope of the malars, shape and, usually, size of the orbits, size and shape of the mandible, and thickness of the tympanic plate. In Eskimo skulls, whether long or short, these features, though difficult to express in metrical terms, have a characteristic and easily recognized appearance. It has often been asserted that morphological characters of this kind are adaptive modifications that have resulted from vigorous use of the jaws and teeth. This, how-

ever, has never been proved, any more than the corollary explanation that the peculiar Eskimo skull form is itself the product of these same functional forces. The cranial and facial features mentioned are known to be hereditary, for they occur in children and infants as well as adults, and as they are already present in the earliest Eskimo crania, it is difficult to see how they can be explained as functional adaptations.

It is not too much to require that theories on as important a subject as the racial origin of the Eskimo should utilize all the available evidence. However, it cannot be said that any of the theories thus far advanced have fulfilled this requirement. The attempts that have been made to prove an Indian origin for the Eskimo are subject to criticism on several counts: (1) Measurements of living Indians and Eskimos have been compared without inquiry as to the possibility of white mixture, even though photographs of the particular Indians and Eskimos and the history of long-continued white contact leave no doubt that in some cases extensive mixture of this kind has occurred; (2) relationships have been postulated on the basis of head and face measurements alone, without taking into account differences in bodily proportions, nonmetrical facial features, and general physiognomy; (3) widely separated Eskimo groups, or even the Eskimo as a whole, are assumed to have originated from an Indian stock such as Cree or Chipewyan, 1,000 or more years ago, because the Hudson Bay Eskimos, whose territory adjoins that of the Indians, resemble the latter in certain head and face measurements, without considering the alternative explanation that the resemblances in question may be due to recent intermixture; (4) to explain certain metrical resemblances between distant Eskimo and Indian groups, large-scale migrations of Indians from the interior of Canada to the Arctic coast have been postulated, sufficient to absorb or replace the original Eskimo populations, though the evidence of linguistics, archeology, and physical anthropology shows that no such Indian irruptions could possibly have occurred; (5) comparisons of Eskimo and Indian crania, leading to theories of common ancestry of the two groups, like the similar comparisons on the living, have considered measurements alone, to the exclusion of morphological, nonmetrical features that are characteristic of Eskimo crania but not of Indian; (6) and finally, none of the theories advanced—except the dubious functional theory—explain the origin of the long, narrow, and high-headed type characteristic of Greenland and the earlier periods in northern Alaska.

We will search in vain in America for any cranial form from which the highly specialized Eskimo type may likely have been derived. There are numerous long-headed Indian groups such as the Lagoa Santa type of Brazil, the early California and Texas Indians, and some of the northeastern tribes who in skull dimensions alone resemble the Eskimo. The resemblance, however, does not extend to

the face, which in all cases is entirely different, nor do any of the Indian crania possess those minor but distinctive Eskimo features such as the thickened tympanic plate, the high frequency of mandibular and palatine tori, or the very narrow and "pinched-up" nasal bones.

In the Old World the situation is almost reversed. We know of no living Asiatic people who have skulls of the very long, high, and narrow Eskimo type. The Eskimo face, on the contrary, is so distinctly Mongoloid that we can only conclude that it has an Asiatic ancestry. The living Eskimos exhibit a number of other obvious Mongoloid features such as skin color and hair, nose form, high frequency of the epicanthic or Mongolian fold of the eye, and shortness of arms and legs in relation to the trunk. These features bring the Eskimos into close relationship to the Asiatics, making them in fact the most Mongoloid of all American aborigines. Most anthropologists would probably agree with Hooton that if it were not for the Eskimos' non-Mongoloid skull form they should be classified as an Asiatic rather than an American race.

It is not unlikely that eventually the Eskimo skull form also will prove to have Asiatic affinities. In recent years Debets and other Russian anthropologists have described a long-headed population from the Neolithic sites around Lake Baikal, sites which, as we have seen, contain cultural material closely resembling that of the earliest known Eskimos. In 1939 Hrdlička studied these Siberian skulls and described them as closely related to the American Indian (1942). He does not bring the Eskimo into the comparison, but it is to be noted that while the majority of the 33 Siberian male skulls are quite low-vaulted, 8 of them are almost as high as the very high-vaulted Birnirk crania. These eight skulls are likewise above the average in length, and some of them are described as having keel-shaped vaults and narrow noses, features suggestive of the Eskimo. Until photographs and a fuller description of the Siberian crania are available the significance of these resemblances must remain in doubt. The present evidence suggests, however, that these early Siberians, whose culture was undoubtedly related to that of the earliest Eskimos, included as a minority element a physical type corresponding rather closely to that of the Eskimo.

The thickened tympanic plate and the mandibular and palatine tori also occur more frequently in Eurasia than in America. The tori are found most often among the Chinese and Japanese (mostly prehistoric), the Ainu, Ostiak, Lapp, and Scandinavians of the Viking period. The thickened tympanic plate occurs with less regularity among the Mongoloid groups but shows a high incidence again in iron-age and Medieval Norse crania from Norway, Iceland, and Greenland. Two

of the oldest skulls from northern Europe, from a Mesolithic site on Lake Ladoga near Leningrad, have quite thick tympanic plates (Inostrantzev, 1882). Moreover, one of these skulls shows a striking resemblance to the generalized Alaskan Eskimo type in the shape of the face and the contour of the vault. It may be a point of some significance that the thickened tympanic plate and the mandibular and palatine tori, which are more characteristic of the Eskimo than of any other race, are found to a comparable degree elsewhere only among prehistoric and early historic peoples in regions where Eskimo cultural resemblances also occur.

LANGUAGE

The Eskimo language is divided into two branches, Eskimo proper and Aleutian. The main branch includes the various Eskimo dialects spoken from south Alaska eastward to east Greenland. The Aleutian language differs so sharply from the other Eskimo dialects that for a long time its Eskimo affinity was questioned. However, it is now recognized as being remotely related to Eskimo, just as is the Aleut physical type and culture.

Within the Eskimo group itself the greatest linguistic differentiation is found in Siberia and south and west Alaska, from Prince William Sound north to Norton Sound. Here there are several quite distinctive dialects that differ considerably from those spoken by the other Eskimos. Beginning at Bering Strait we find a different situation, for from this point eastward to Greenland and Labrador the dialects are mutually intelligible. The Alaskan Eskimo dialects north of Norton Sound are actually closer to the dialects of Greenland and Labrador than to those of the adjacent Yukon region. It is difficult to believe that such remarkable linguistic uniformity over so wide an area could have persisted for any great length of time. Rather, it is a strong indication of fairly recent contacts and intercommunication among the northern Eskimos. Perhaps the best explanation is to be found in the movements of the Thule culture. The uniformity was probably first established when the Thule Eskimos moved east from Alaska to Canada and Greenland, and then still further strengthened by a return movement to northern Alaska within the past few centuries, a supposition for which there is also considerable archeological evidence.

In addition to the greater linguistic diversity in south and west Alaska, the dialects there and in Siberia are of a more archaic character than those in the Central regions and Greenland. Thalbitzer, Jenness, Bogoras, and Sapir are all in agreement in viewing this as indicating that the probable center of Eskimo dispersion was in Alaska or Siberia.

It has not been possible to prove a relationship between the Eskimo and any American Indian language. On the other hand, a number of linguists, such as Rasmus Rask, Henry Rink, and C. C. Uhlenbeck, have pointed out resemblances between Eskimo and the Uralian languages of northern Eurasia. The most elaborate attempt to demonstrate a relationship between Eskimo and Uralian was that of Sauvageot in 1924. Most students of Eskimo linguistics were unconvinced by the particular points of similarity adduced by Sauvageot—even Uhlenbeck, who believed that such a relationship existed.

In 1907 Uhlenbeck pointed out a number of striking word similarities between Eskimo and proto-Indoeuropean. Recently he has returned to a consideration of the problem and brought together a much larger body of evidence in support of his theory (Uhlenbeck, 1935, 1942-45). Though Uhlenbeck does not claim a genetic relationship between the two stocks (as he does in the case of Eskimo and Uralian), he believes that the lexical and grammatical resemblances noted are evidence of a very old Indoeuropean influence on Eskimo. Thalbitzer, the foremost authority on Eskimo linguistics, who had been skeptical of Uhlenbeck's earlier attempt, has now subjected this later and more complete study to searching criticism (Thalbitzer, 1945). After rejecting a number of the suggested parallels, Thalbitzer decides that there remains a great deal of evidence in support of Uhlenbeck's argument. If Uhlenbeck and Thalbitzer are correct, the evidence of linguistics is now to be aligned with that of archeology, and to a certain extent physical anthropology, in showing that the original home of the Eskimos was in the Old World. For if the Eskimo language, aside from its possible Uralian affinity had also been subjected to Indoeuropean influence in ancient times, the Eskimos must then have been living in fairly close contact with people speaking these languages, and this must have been somewhere in northern Eurasia, far to the west of the territory they now occupy.

SUMMARY

Our review of the available archeological evidence has led to the conclusion that the deepest roots of Eskimo culture extend back to the early Neolithic of Siberia and the Mesolithic of northern Europe, a conclusion supported by the data of physical anthropology and linguistics. As the Mesolithic rests on an Upper Paleolithic foundation, Eskimo culture might properly be traced to that remote period. The relationship with the Mesolithic, however, is more direct, and we are on firmer ground in seeking the origin of an important segment of Eskimo culture in this later stage and in the related Siberian Neolithic.

There is still a wide gap both in time and space between the oldest known Eskimo cultures and the early Siberian Neolithic. If our reconstruction is correct, we would expect to find somewhere in the vast stretches between Lake Baikal and Bering Strait traces of the later Neolithic peoples who followed the great Siberian rivers from their headwaters down to the Arctic coast. There, under stimulus of Arctic conditions encountered between the Kara and East Siberian Seas, they developed the rudiments of the maritime culture that later found its fullest expression among the Eskimos. Living in permanent settlements of underground houses at the relatively few places suitable for the hunting of sea mammals, these early ancestors of the Eskimos probably remained at first in more or less isolated groups and continued the Neolithic mode of life, which in the Baikal region, meanwhile, was giving way to bronze- and iron-age cultures. In this connection we note the evidence presented by Cernecov and Zolotarev that in late Neolithic times, but still before the intrusion of the nomadic reindeer-breeders, the coasts and rivers of northern Siberia continued to be occupied by isolated and sedentary groups whose underground houses, pottery, and hunting and fishing techniques were essentially Eskimo in character (Cernecov, 1935; Zolotarev, 1938; Collins, 1937, 1940; Jenness, 1941).

The final development and elaboration of Eskimo culture took place at Bering Strait, a region abounding in game—walrus, seals, caribou, birds, fish—and in every way more suitable for human occupation than the north coast of Siberia. For a people equipped to utilize the resources of the sea, Bering Strait was one of the richest hunting territories of the world. Considering this and the fact that it was also accessible to culture influences from the south, it is not surprising that Bering Strait became a center of high cultural development.

The two factors, local culture growth and stimulus from outside, combined to produce the elaborate and specialized Old Bering Sea and Ipiutak cultures. Many of their individual features we know were of local origin, because they are either unique or are shared only with later Eskimo cultures. Nor is there reason for assuming that any large segments of the culture, such as the highly developed art complexes (in contradistinction to their individual elements) were brought in toto from some unknown outside source.

But, granting the potency of local culture development at Bering Strait, there remains much that is difficult to explain on this basis. For instance, the raised "eye" designs that are so prominent in fully developed Old Bering Sea art are so much like those of early Shang and Chou art in China that a connection of some kind seems probable (Collins, 1937, p. 298). Ipiutak art has even closer Asiatic affinities. As Larsen and Rainey have shown, some of the Ipiutak designs and carvings, especially of animals, are strongly reminiscent of Scytho-

Siberian and Permian art. Other Ipiutak features suggest Chinese influence: masklike ivory carvings, long ivory rods resembling back scratchers with one end carved to represent a human hand, and ivory eyes, nose plugs, and mouth covers found with burials (Larsen and Rainey, 1948, pls. 49, 54, 55, 73, 98).

Features such as these suggest that probably in the first millennium B. C., or later, long after the rise of civilization in China, the Eskimos at Bering Strait received strong cultural impulses from interior and eastern Asia. If we visualize the early Baikal Neolithic as the tap-root we can imagine these later Asiatic influences as forming a lateral branch which, rooted in the richer and more diversified cultural environment of a later time, contributed its important part to the synthesis of Eskimo culture.

CONCLUSION

On theoretical grounds we are forced to assume that the Indians as well as the Eskimos reached America by way of Bering Strait. Until recently there had been no direct evidence for this assumption as no remains other than Eskimo had been found there. Probably, in the centuries before Eskimo culture had crystallized and established itself in northeast Siberia, some Neolithic groups crossed the Strait by boat or on the ice and penetrated south and east into North America. The presence of Indianlike skulls in the Siberian Neolithic and of Old World culture traits such as stone gouges and comb-stamped pottery in the inland and eastern areas of North America, makes this a distinct possibility. Gjessing (1914) is probably correct in viewing gouges, comb-stamped pottery, and possibly certain kinds of petroglyphs as part of a culture wave which, avoiding the Arctic coast, spread from the inland regions of Eurasia to the interior of North America. Such traits could have passed over at Bering Strait without having become firmly established there, and hence would have left no trace, or they may have left signs of their passage that have not yet been discovered.

Cultural connections of this kind, which are indicated by discontinuous distribution of traits in the Old World and America, and which have no demonstrable connection with the Eskimo problem, are not within the scope of the present paper. Nor is there any point in speculating on still earlier migrations that brought the first human inhabitants to this continent, presumably not across ice or water but over the great land bridge which in Pleistocene and early postglacial times stretched for 1,000 miles from southern Bering Sea north into the Arctic Ocean.

The oldest cultural remains thus far found in the Bering Sea region are those of the Denbigh Flint Complex, a microlithic culture discovered in 1948 by J. L. Giddings, Jr., at Cape Denbigh, Norton

Sound. In 1950 two more sites of the same complex were found in the Brooks Range in the interior of northern Alaska. The Denbigh Flint Complex is apparently post-Pleistocene in age, and though considerably older than any known Eskimo culture, has an important bearing on the problems we have been discussing. We may therefore consider the implications of these new finds.

When a relationship between the Mesolithic and early Neolithic cultures of Eurasia and the earliest Eskimo cultures in Alaska was first postulated (Collins, 1943), it seemed necessary to emphasize that the resemblances did not extend beyond the Eskimo sphere, in time or in space. Previous theories of the Siberian Neolithic as the primary source of American culture in general, even of its earliest manifestations, seemed invalid for the following reasons:

(1) The Siberian Neolithic, even if it rested on an Upper Paleolithic base as Okladnikov contended, was ecologically recent. The animal bones from the Neolithic sites were all of existing species—deer, elk, bears, reindeer, birds, and fish. The same was true of the bones from the oldest Eskimo sites—mainly seal, walrus, caribou, dogs, foxes, birds, and fish, all of species still living. The frozen muck in the vicinity of some of the Eskimo sites contains abundant remains of a Pleistocene fauna, but the Eskimos knew these animals just as we do—as fossils; for the occasional mammoth teeth and pieces of tusks that are found in the old Eskimo middens are always fossilized, unlike the other bones. In contrast, the Paleo-Indians on the High Plains hunted these now extinct mammals.

(2) The relative recency of the Siberian Neolithic, even its earliest stages, was indicated by the absence of burins, which characterized the European Mesolithic, and by the presence of small, symmetrical, finely chipped arrow points, which resembled Eskimo and later American Indian types. These and other Siberian Neolithic traits such as pottery, polished-stone adzes, and the reinforced bow, could hardly have been the possessions of a people ancestral to the earliest Americans.

(3) Physiographic changes of considerable magnitude have occurred since Sandia Cave, the Lindenmeier site, and other Paleo-Indian sites were occupied. This apparently was not true of the early Neolithic sites around Lake Baikal, and in the Eskimo area such changes have definitely been of a minor and local character. Even the oldest Eskimo sites are located along existing shore lines, showing that they were established when the relation of land to sea was essentially the same as today. Any older coastal sites, established when sea level was lower, as it was during glacial and early postglacial times, would now be under water.

The evidence then existing seemed clearly to indicate that the relationship between the early Siberian Neolithic and early Eskimo cul-

ture was an exclusive one, and that there was no demonstrable connection between either of these and the far more ancient Paleo-Indian cultures of the western plains. These conclusions still stand insofar as they pertain to the stages of Eskimo and Siberian Neolithic culture thus far known. However, the problem has assumed larger dimensions, and possibly a different orientation, as a result of the recent discoveries in Alaska to which we have referred. In 1948 at Cape Denbigh, on Norton Sound, Giddings discovered an early microlithic culture with definite Mesolithic affinities, older than and possibly ancestral to both Eskimo and Siberian Neolithic, and also connected in some way with Folsom and Yuma. In the summer of 1950 two other sites yielding the same types of stone artifacts were found in the vicinity of Anaktuvuk Pass in the Brooks Range in the interior of northern Alaska by William Irving and Robert J. Hackman (Solecki and Hackman, 1951).

Giddings' early material was found at the base of an old site on Cape Denbigh known to the Eskimos as Iyatayet. The uppermost materials were relatively recent and overlaid deposits representing the Early Punuk period. Beneath this was a clay layer containing flint implements of Ipiutak type together with others resembling prehistoric South Alaskan and Dorset types, and also small stone lamps, round to triangular in shape, and thin, hard pottery fragments decorated with a dentate or simple check stamp. Next came a sterile layer of laminated sandy clay from 2 to 18 inches thick, and underlying this was the basal deposit—a thin stratum of pebbles and flints representing a microlithic industry unlike anything previously known from the New World. This basal "Denbigh Flint Complex" comprised (1) delicately rechipped lamellar flakes, tiny blades made from such flakes, and the polyhedral cores from which they had been struck off; (2) blades of generalized Folsom and Yuma types; and, most surprising of all (3) a large assortment of burins, a specialized form of stone implement never before found in America, the distinguishing feature of which is a restricted, stout edge designed for cutting deep grooves in bone and similar material. The Denbigh burins comprise a number of types, most of them closely resembling those from Upper Paleolithic and Mesolithic horizons in the Old World (Giddings 1949, 1951).

The Cape Denbigh discovery is of great significance in connection with the problem of Early Man in America. It links Folsom and Yuma with the lamellar flake-polyhedral core industry found at the University of Alaska campus site and elsewhere in central Alaska (Rainey, 1939), in the Brooks Range (Solecki, 1950), and at Mesolithic sites in Mongolia (Nelson, 1937) and in Sinkiang, Manchuria, southern Siberia, Kamchatka, and Hokkaido (Watanabe, 1948). It tends to place all these cultural manifestations in a Mesolithic setting,

and provides the first clear evidence (mainly burins) of early Old World stone techniques associated with early American cultures. It is too early to speak of the age of the Denbigh Flint Complex vis-à-vis Folsom and Yuma. On the one hand, the presence of burins suggests priority for the Alaskan site. However, we cannot ignore the possibility that Folsom and Yuma may have preceded the Denbigh Complex and that the few blades of those types found at Denbigh sites were vestiges from an earlier period. The reported occurrence of Yuma-type blades in frozen muck of Pleistocene age near Fairbanks (Rainey, 1939) lends support to this supposition. Whatever the relationship may be, the fact that Folsom and Yuma are associated with an Arctic culture characterized by Paleolithic-Mesolithic types of implements suggests that part at least of the story of Early Man in America may eventually be unfolded in Arctic Alaska, the original point of entry. The more recent finds near Anaktuvuk Pass extend the range of the Denbigh Flint Complex and are of particular importance as showing the probable route these early people followed into the heart of the American Continent.

Though the Denbigh Flint Complex is older than anything known from Alaska, with the possible exception of sporadic finds from the frozen muck that have turned up in the course of mining operations (Rainey, 1939), present indications do not point to any very great antiquity, at least for the Anaktuvuk and University campus sites. At both of these places the flint implements are found in or immediately below the surface sod. As the Anaktuvuk region was glaciated, the sites there could have been established only after the last ice recession, but whether soon after or much later there is no indication at present. The Cape Denbigh site may of course be older than these inland sites, and perhaps considerably older than the one on the University campus. However, unless there is geological evidence to the contrary, there is no reason to suppose that it was particularly ancient. The presence of Paleolithic-Mesolithic burins and other implements is hardly decisive in this regard. The Denbigh people may only have been perpetuating a Paleolithic tradition in the use of these implements long after it had faded away in the Old World, just as much later the Ipiutak Eskimos continued to use side-bladed projectiles of Mesolithic-Neolithic form several thousand years after they had passed out of use in Eurasia.

The Old World affinities of the Denbigh Flint Complex cannot yet be localized. Its numerous types of Paleolithic-Mesolithic burins suggest a relationship with the European Mesolithic, while lamellar flaking connects it with central and northern Asia. The crucial area is northeastern Siberia. Our knowledge of the pre-Eskimo archeology of this region is very meager, but it seems safe to predict that sites comparable in age and lithic content to Cape Denbigh will eventually

be found there, sites with both lamellar flaking and burins. Such, indeed, may be the Neolithic sites on the Lower Kolyma and Chukchee Peninsula recently reported but not described by Okladnikov (Shimkin, 1949). However, as burins are not mentioned, these sites may represent only a further, extreme northeastern extension of the north Asiatic lamellar flake-polyhedral core complex described by Watanabe (1948).

The significance of the Cape Denbigh and Anaktuvuk finds in connection with the Eskimo problem is not yet clear. They may, however, have important implications for Eskimo archeology. The Denbigh Flint Complex is, of course, very different from, and much older than, what we usually think of as Eskimo. The simplest explanation would be that this complex—an assemblage containing Yuma and Folsom-like blades and Paleolithic-Mesolithic burins, and separated from overlying Eskimo deposits by a sterile layer of clay—had no connection with these later deposits. However, there are reasons for suspecting that there was a connection: (1) It is somewhat difficult to believe that its location directly beneath an Eskimo site was a mere coincidence; (2) lamellar flaking, though absent at Ipiutak, is one of the most characteristic features of the Dorset, a culture which on other grounds appears to represent an older stage than Ipiutak or Old Bering Sea. Polyhedral cores have not been reported at Dorset sites but this may be accidental, for Solberg (1907, p. 39, fig. 14) describes one from Disko Bay, Greenland, in a collection which contains many Dorset types; (3) the Cape Denbigh and Anaktuvuk burins appear to be the prototypes of similar implements found at Dorset sites which were no doubt used as burins; (4) the presence of small, finely chipped side blades indicates that the Cape Denbigh people used slotted bone points, probably arrowheads, with inset blades along the sides, a form characteristic of Ipiutak and the European Mesolithic; (5) one of the Denbigh implements, an obovate blade "carefully retouched on both convex faces and then ground to a strong bevel at the broad end" (Giddings, 1949, p. 89, fig. 2, e), seems to be essentially the same as the characteristic Old Bering Sea implement with strongly bevelled ends which the present writer described as "adz-like scrapers" (Collins, 1937, p. 152, fig. 16, pl. 42, figs. 12-14), and which Larsen and Rainey (1948, p. 85, pl. 10, fig. 1) later found actually hafted as adz blades at Ipiutak; (6) the Denbigh Flint Complex includes short, wide, thin blades closely resembling those found hafted to sealing harpoon heads at Ipiutak. Though the Ipiutak flint technique on the whole is different, Giddings (1951) concludes that "it looks as though Ipiutak has inherited these particular resemblances [the probable harpoon blades, a form of flake knife or scraper, and occasional diagonal flaking] from an earlier horizon represented by the Cape Denbigh finds"; (7) another linkage may also be provided by Larsen's recent discovery in a

Seward Peninsula cave of lamellar flakes associated with slender arrowheads of antler with two long, deep grooves for side blades, a type which is essentially Ipiutak, but undecorated. This cave, discovered in 1948 by David Hopkins, appears to be intermediate in age between Ipiutak and Cape Denbigh.

On the basis of the present evidence it appears that despite the definite Paleolithic-Mesolithic affinities of the Denbigh Flint Complex, a cultural relationship of some kind existed between the early Cape Denbigh people and the Eskimos who later occupied the same region. A similar relationship also existed between the Denbigh Complex and Folsom and Yuma. If our interpretation is correct this means that the hitherto distinct problems of Eskimo origins and of Early Man in America must now be considered in a single frame of reference, one that extends the range and scope of both problems and adds new facets and perplexities to each.

Thus Folsom and Yuma are brought into relationship with an Arctic culture of unknown age, which in turn is related to Mesolithic cultures of Eurasia. As for the other side of the problem, the Denbigh finds attest the antiquity of a number of Eskimo culture traits and strengthen the view that Eskimo culture is basically of Mesolithic origin. At present we can only guess at the extent of the time gap between the Denbigh Flint Complex and the oldest known Eskimo cultures, but it is probably a difference to be measured in millenniums rather than centuries. Until that point is determined and until more information is available for Siberia, the role of the Denbigh Complex in the formation of Eskimo and Siberian culture will remain obscure. We can only say that it is much older than, and yet in some way related to, Eskimo, just as it also clearly antedates and in all probability represents a stage of culture ancestral to the early Neolithic cultures around Lake Baikal and the Ural Mountains which show such close resemblances to early Eskimo.

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ARCHEOLOGY AND ECOLOGY OF THE ARCTIC SLOPE OF ALASKA

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[With 6 plates]

Of great interest to students of prehistory in America is the problem of man's migrations from the Old World to the New. It is virtually undenied that as far as we know, prehistoric man entered America from Eurasia. Until lately one of the most baffling situations was the fact that we had little acceptable evidence to substantiate any claims for his antiquity in Alaska, the threshold of entry.

We can now state definitely that reliable evidence has been found in various parts of Alaska and the Yukon Territory that validates assumptions that pre-Eskimo and pre-Athapascan Indian peoples lived there. However, since the scope of the subject is broad, and in view of the recency of the finds, total reports have not been made available to date. Therefore we shall deal with one facet of the problem in the Arctic with which the writer is most familiar. This is the inland archeology of northern Alaska, or that part of the territory aptly called the "north slope," which lies between the Brooks Range and the Arctic Ocean (fig. 1). We have already sketched the anthropology of the north slope in a brief report and have written a preliminary report on the archeology of two rivers in the western part of the same region (Solecki, 1950a, 1950b). These reports were based on data obtained during a field trip made during the summer of 1949.

Significant archeological finds were made during the summer of 1950 in northern Alaska, but they cannot be presented in this paper because all the data are not yet available. These data include the discovery of artifacts typologically similar to Giddings' (1949) Cape Denbigh Flint Complex near Anaktuvuk Pass, and the finding of polyhedral cores and Folsomlike projectile points in the headwaters of the Noatak River. Although the additional archeological data have broadened our perspective of the cultural prehistory north of the Arctic Circle, the ecological background has not been changed.

The interrelationships between man and the plant and animal kingdoms, existing in a similar geographic and climatic environment, are of interest to students of Eurasiatic-American cross ties, and an appraisal of ecological factors is a necessary adjunct to the study.

Complications naturally arise when an estimate of prehistoric cultures is desired, since we not only have a problem of synchronic levels of culture plus environmental relationships, but also a question of depth in time. In order to present a coherent picture of the past life of man in northern Alaska, the archeology must be equated in terms of other related disciplines. These include geology, climatology, paleontology, and botany. Possible hypotheses arising from various considerations of the problems are many, because at present, in many cases, we can only make guesses. We shall appraise briefly some of the few recognized hypotheses with special bearing on the physical environment of man on the north slope, considering them from both the biological and geographical standpoints.

We know that in this region, as elsewhere, the environmental factors were continually changing. These changes certainly affected man's ecological background. Thus, hand in hand with the changing archeological data must be considered the changing ecological basis of the study. Such a basis is an extremely important one in inland Arctic archeology. In order to understand and evaluate it appreciatively, we must establish the motivating economy. In the region under scrutiny there seems to have been but one practicable economy to follow—that of hunting and foraging. In the face of superimposing conditions of the environment, no other alternative was possible for the natives of the region except migration. Hence, a dynamic ecology played a distinctive role in the prehistory of inland northern Alaska.

As defined here, ecology is essentially an observational science—the science of communities or the science of relationship of organisms to environment. According to Charles Elton, one of the leading English ecologists, there seems to have been much emphasis upon human ecology, in a restrictive sense, in anthropological work. "Human ecology has been mainly concerned almost entirely with biotic factors, with the effects of man upon man, disregarding often enough the other animals amongst which we live" (Elton, 1939, p. 190). This may be so, especially in the light of studies of preliterate peoples, the investigation of whose customs, folkways, and other ethnologic features was presumed to shed understanding on the problems of our more complex contemporary societies. For instance, it has been said that primitive cultures are "the only laboratory of social forms that we have or shall have" (Benedict, 1934, p. 17). The latter theme has been recognized and espoused by anthropologists the world over. Although the environment of the people concerned is usually mentioned, it seems that the physical background and its biological influences are not accorded the important role that they should be given. This is especially true in reference to long-time changes in plant and animal life and their effects upon man. In this regard, since prehis-

tory antedates history, it remains for the archeologist to reconstruct the ecological ties of past cultures.

Wissler (1924, p. 312) viewed the human ecological problem as the correlation of "the facts of nature with the facts concerning man's behavior." As one of his classic examples, he pointed out (*ibid.*, p. 314) that primitive hunting cultures are found to be based upon some natural resource, such as that of the Plains-dwelling Indians upon the bison of North America. Bison provided the chief food and was the source of skin clothing and of shelter. The correlation

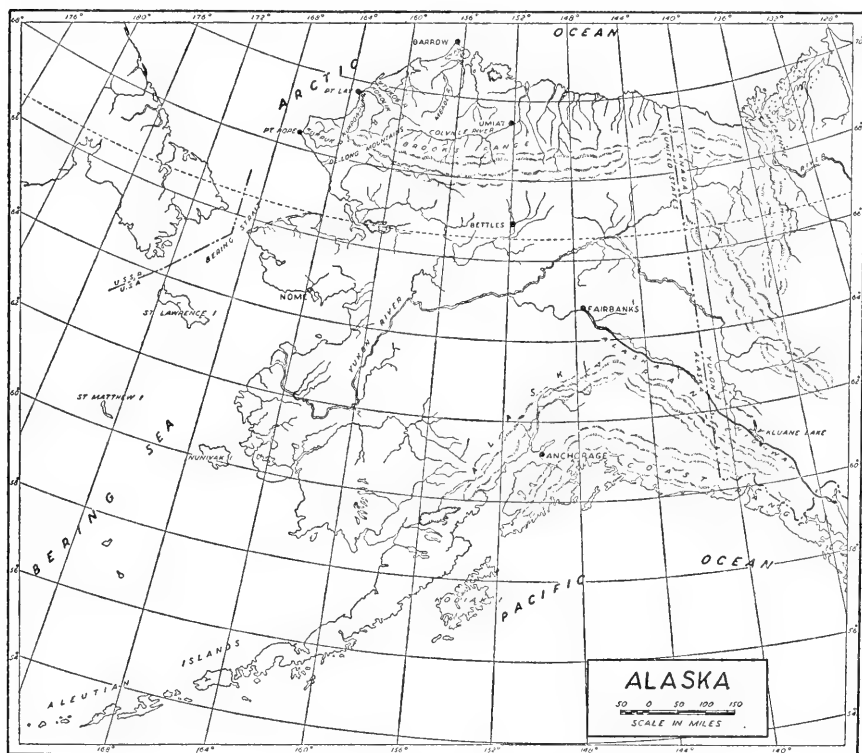


FIGURE 1.—Map of Alaska.

of natural and cultural areas has its limitations, which can be strained too far when trying to explain man's behavior. However, we cannot dismiss entirely the part environment plays in man's life (Hawley, 1950, pp. 84, 90).

If we treat human ecology as part and parcel of the broader and more inclusive study of animal ecology, several interesting considerations are brought to light. Elton (1949, p. 920) posits that it is necessary to study the *whole* animal community in a locale in order to get a total picture. "It would therefore seem likely that intensive work, carried out completely on very simple communities such as

those of Arctic regions or deserts, would afford the strongest chance of discovering the fundamental laws governing the interrelations of animals and therefore the regulation of their numbers" (*ibid.*, p. 921). Huxley (Elton, 1939, Introduction) says that Elton has been fortunate in having field experience in the Arctic, where the ecological web of life is reduced to its simplest and where complexity of detail does not hide the broad outlines. It seems valid to assume that conditions affecting animal life in simpler communities would also influence the animal's host, man.

The first of the environmental factors controlling the occurrence and numbers of animals in the Arctic to be considered are the climatic conditions. These, of course, do directly act upon animals, but a great deal of this influence is felt indirectly through plants leading back to the ultimate source of energy, the sun. As far as the animals are concerned, however, the whole character of the climate is determined by the plants. Different areas of plant communities may set apart animal zones or "life zones," such as the habitat of the Barren Ground caribou on the north slope of Alaska, which is set apart from the moose zone farther to the south and closer to the timber line. This distinction of one life zone as compared to another may be the difference of one kind of human ecology from another. This should be qualified somewhat. Humans are but indirectly tied to the plant life of their habitats. Therefore, they may change habitat at will. The latter course rests upon the proposition that other means of supplanting previous economy are to be found and that no hostile peoples or geographical barriers exist to thwart migration.

We are quite certain that man began to enter the New World some time or times in the latter part of the Pleistocene epoch and the beginning of the Recent epoch in geologic time. Several successive glaciations—at least four—alternating with thaws, capped the northern end of the earth principally in the more elevated regions. In North America, man's entry was subsequent to the last glaciation, which occurred about 25,000 or more years ago. It is presumed that there remained a great deal of ice on portions of the earth's surface when Early Man came to America. This ice undoubtedly had a bearing on the routes used by the migrating incomers (Roberts, 1940, p. 102). The fossil records show clearly that there had been an interchange of fauna between Asia and America. Man evidently journeyed in one direction only, eastward to this hemisphere, and probably over a land bridge during the earlier stages.

As Ivar Skarland (*n. d.*, p. 126) succinctly pointed out, a land bridge was present only during glacial stages. This land bridge was more literally than figuratively a truth, to judge by the strength of the arguments in its favor. The now-familiar hypothesis is that the Ice Age, in locking the water in glaciers, lowered the sea level enough to permit

the emergence of a land bridge between Asia and America. That this was not improbable is shown by several facts. Only some 56 miles of water separate both continents today, with a couple of islands between the narrowest point. The minimum recession of sea depth necessary for reemergence of the bridge is only about 120 feet. Furthermore, a true land bridge would have been required to allow the intercontinental exchange of so many fauna. It may be assumed as a possibility that as the animals migrated into the New World, the first Americans and their successors followed. The first or earliest Americans are collectively distinguished by the title of "Early Man" or "Paleo-Indian." It is certain that all animals did not have equal opportunities for reaching the intercontinental highway, nor were all equally equipped with or adapted to the necessary survival qualities, as George Gaylord Simpson (1940) has pointed out. This type of screening may be termed a "filter bridge" (fig. 2). Early Man undoubtedly crossed into the new continent unknowingly, with no preconceived notions of exploration and followed the unglaciated portions of America. His route was presumably controlled by the topography and the extent of the dispersion of game.

We assume that the first American, principally a hunter of herbivores—like the carnivores of the region—was more interested in the larger grass-eating mammals. The latter, in turn, depended on the existence of suitable fodder. We feel that man did not consciously direct his traffic in one direction or another but expanded his territory with the dispersion of his game. Thus, the usual definition of migration with a view to residence does not strictly apply here. Douglas Leechman (1946, p. 386) aptly states:

Diffusion would be a better term than migration. In all probability, the first people to cross the Bering Strait, and to make America their permanent home, camped not very far from their landing place.¹ Gradually the surrounding district became known to them and, as a result of hunting expeditions in the neighborhood, attractive camp sites and fishing stations would be discovered. As their children grew up, and had families of their own, they would settle a few miles farther upstream or inland, thus diffusing gradually throughout the whole district. The movement of an amoeba by means of pseudopodia gives us an excellent illustration of the type of migration involved.

It may be objected that this is altogether too slow a process, but an average of as little as two miles a year would carry people from the Yukon down to the bottom of South America in approximately 5,000 years.

Leechman's estimate may be a little too conservative when we consider some of the archeologically known shifts of populations in America. It is also apparent that the process was not quite so simple.

¹ Evidently Leechman believes that Early Man established a beachhead, crossing over water and not a land bridge. This may have been true for man, but not for other mammalian life. Present-day travels of Eskimos between the two continents by boat are well known.

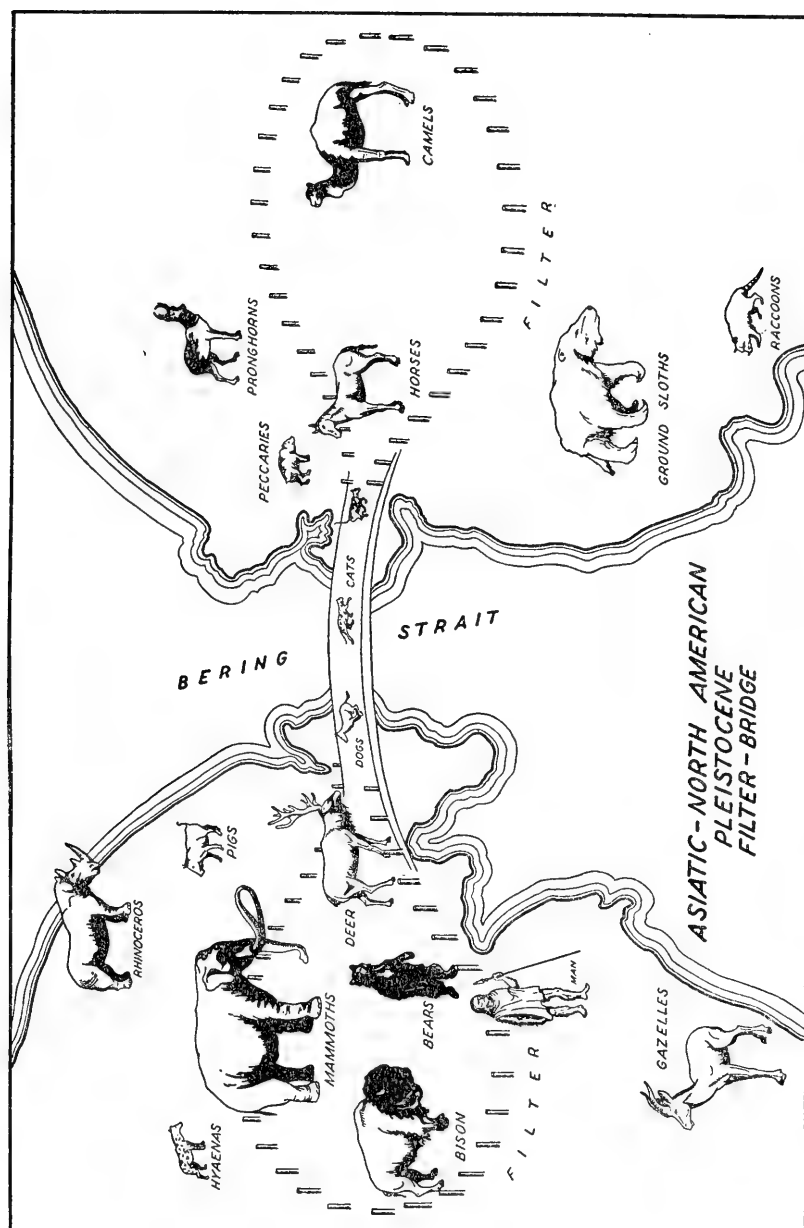


FIGURE 2.—Diagrammatic conception of the Asia-North America Pleistocene filter-bridge. Adapted by permission from George Gaylord Simpson.

Suffice it to say, however, we do know that the primitive populations did make a vast swing through the continents well before the time of Columbus' discovery. We are assured that the Pleistocene climate in the unglaciated portions of northern America was not greatly different from that of today; nor is there any conclusive evidence that the present flora was entirely absent during any phase of the late Pleistocene epoch (Skarland, n. d., pp. 72 and 74). The presence or absence of flora suitable as forage for particular groups of herbivorous mammals very likely indirectly controlled man's movements.

THE COUNTRY

Physiographically, the north slope, occupying an area of about 70,000 square miles between the Brooks Range and the Arctic Ocean, is divided into three provinces. All extend north of the 68th parallel and are beyond the Arctic Circle. These provinces are the Brooks Range Province, the Arctic Foothills Province, and the Arctic Coastal Plain Province (fig. 3).



FIGURE 3.—Map showing the physiographic provinces of the north slope of Alaska. Reproduced by permission of the U. S. Geological Survey.

The Brooks Range, the northernmost mountain range in Alaska, is composed of rugged, glaciated mountains. Its snow-capped peaks in the eastern section rise to about 9,000 feet. Representing the Alaskan counterpart of the Rocky Mountains, this range is composed of highly indurated and strongly resistant Paleozoic rocks. There are about 30 or 40 small glaciers of about 2 or 3 miles in length still lingering in the mountains. Fronting the Brooks Range are several large mountain-fed lakes that empty into the north-flowing rivers. The whole of this province bears evidences of glaciation from one end to the other of its 600 miles' length. Three good passes—Howard Pass, Survey Pass, and Anaktuvuk Pass—breach the middle of the range and connect the drainages on both north and south sides of the divide. The divide may be crossed at other points but with considerably more difficulty.

The Foothills Province (pl. 2), characterized by low hills and ridges, is divided into two sections. The more elevated southern foothills border the mountains with elevations up to 3,000 or 3,500 feet, while the more subdued northern foothills section averages from about 400 to 600 feet in height. These foothills, made up mainly of Mesozoic rocks, are less deformed and less resistant than the mountains. There are many crustal warpings—called anticlines and synclines—in this province, which have their axes parallel, east and west. These warpings produce ridges that give the country a linear aspect when viewed from the air, much like the Alleghenies in Pennsylvania. The folding is intense near the mountains, and the beds of rock stand nearly vertical in places. Farther away from the mountains to the north, where the folding is more gentle and the beds lie nearly horizontal, the hard layers form steps on the hill-sides or cap the hills. The prominent ridges of the western foothills extend almost continuously for about 225 miles across the western front of the Brooks Range. Except where glacial tongues may have found their way into some of the valleys adjacent to the mountains, this province has not been glaciated.

The third and northernmost province, the Arctic Coastal Plain Province—also never glaciated—is a low-lying prairie-type area that was once submerged under the sea during late geologic times of the Quaternary period and later uplifted. No thick deposits of marine material were laid down (Smith and Mertie, 1930, p. 238). The monotonous flatness of this province, extending to about 70 miles inland from the coast, is relieved by a few isolated knobs and hills. These hills are generally about 50 to 100 feet in height, and a few reach 300 feet. The deposits of the coastal plain are composed of unconsolidated sands, gravels, and clays. They are dominantly alluvial stream deposits and probably include some glacial and interglacial deposition. There are deposits of Pleistocene sands near the coast, called Gubik sands, which are rich in fossil life. They are of wind-blown origin, or loess. It is conceivable that there may be found some evidence of Ancient Man in the upper layers of these sands. This coastal region, owing to its flatness, naturally has the poorest drainage of the three provinces. It is characterized by its wetness, many pools of standing water, lakes, and sluggish and meandering streams. The general wetness is due to both poor surface drainage and the permafrost, or permanently frozen ground, which extends from a few feet below the surface to a depth of almost 1,000 feet in some places. A phenomenon called frost-wedge (pl. 1), a wedge-shaped mass of subsurface ice, is common in the Arctic.

The climate of the north slope is arid, with a precipitation of only 5 to 7 inches. Although there is little rain or snow, the air is frequently filled with a misty haze in summer. The only explanation

for the failure of the Brooks Range glaciers to cover the Arctic coast was this deficiency of precipitation. The area between the Brooks Range and the Alaska Range, which extends inland from the Bering Sea, was similarly deficient in precipitation (Flint, 1948, p. 222).

As we know, the Arctic winters are long and the summers short, with a correspondingly short period of thaw; hence, only the upper ground surfaces soften in summer. The frigid temperature plus the aridity permit the preservation of organic matter for deceptively long time spans. Physiographic changes and over-all climate changes are also very slow in the Arctic.

Of the three provinces, the foothills area affords the best routes for overland travel parallel to the mountains in all seasons. Stream drainages, tributaries of the main north-flowing rivers with partial exception of the Colville, are oriented on the east-west alinement of the ridges. The coastal plain is difficult to negotiate overland during summer because of the tundra lakes and bogs. The mountains are also natural barriers, traversable only at several of the passes. Viewed today, the north slope of Alaska presents a barren, dun-colored aspect, for it is north of the timber line. There are small stands of stunted willow near the water courses. The dreary landscape is relieved in summer by an almost spontaneous growth of colorful flowers that carpet the surface. Lichens and mosses clinging to rocks in the hills present splotches of bright hue.

The major drainage systems of this region, again with partial exception of the Colville, flow northward, controlled by the slope from the mountains to the coast. They are called consequent streams. The Colville, the largest river in the north, flows eastward at its upper part where it is controlled by a weak bed of rocks. It changes course and flows northward to the sea at its lower reaches. These rivers flow in broad valleys in the foothills section, cutting across ridges to the lower coastal plain where the gradient drops and they become braided and sluggish. It is these same rivers that furnished the highway for the inland Eskimos. They boated down the rivers in spring after the ice break-up, returning in fall to their winter homes in the hills and mountains before the rivers froze over. The Colville River was especially important as a connecting trade and travel route between Kotzebue on Kotzebue Sound and the mouth of the Colville. One of the several good passes habitually used was Howard Pass, joining the headwaters of the Etiviluk River, an upper branch of the Colville, and Noatak River. The latter, flowing west and southward on the other side of the Brooks Range, empties near Kotzebue.

Although the short cuts through the mountains were excellent for the use of Eskimos and their immediate prehistoric predecessors, it is unlikely that they were used by Early Man. The mountain valleys were probably still covered by glacial ice at the time of his entry. On

the other hand, we cannot gainsay that the nomadic hunters of that time used the mountain passes during periods of glacial regression. These same passes over the divide were used recently—in fact, are still being used at the present time—by herbivorous mammals, principally caribou in their annual migratory wanderings.

There is a sharp ecological border between the tundra-covered north slope and the timbered country on the southern side of the divide. The north slope, however, was not always treeless and desertlike, because spruce logs have been found in deposits of Pleistocene age on the coastal plain and along inland rivers (Smith and Mertie, 1930, p. 254). In contradiction to prevailing beliefs, Skarland feels that the spruce timber could have grown during a glacial stage of the Pleistocene rather than in an interglacial stage or stages (Skarland, n. d., p. 82). He also believes (*ibid.*, pp. 79–81) that the Bering Sea and Arctic regions were warmer during glacial stages than they are today.

A minor period of warmth in the Arctic in more recent history is called by the geologists and climatologists a Climatic Optimum. It dates back about 7,000 years. This period was marked by a general amelioration of the temperature when it was apparently warmer in the Arctic than it is now (Brooks, 1949, pp. 364, 370). However, we do not have any geological or paleobotanical evidence that it was warm enough to induce the growth of timber on the Arctic slope. Since the time of the period of transitory warmth, the climate had apparently become somewhat colder, a fluctuation that recently seems to have swung in the other direction. Investigations have shown that the timber line is again moving northward in Alaska. Griggs (1937, pp. 252–253) has given positive evidence of this.

There are fossil remains showing that Arctic Alaska had been inhabited during Pleistocene and post-Pleistocene times by many large and small mammals of which many are now extinct. These include the mammoth, horse, bison, bear, moose, musk ox, caribou, and deer among others (Smith and Mertie, 1930, pp. 251–254). According to Skarland (n. d., p. 114) the musk ox became extinct on the Arctic slope of Alaska only about 80 or 90 years ago.

THE ARCHEOLOGY

From our consideration of the ecological setting of the problem, we are in a better position to interpret the archeology of northern Alaska against the broader perspective of North American prehistory. Geological interpretations of the archeological work indicate that man dwelt in the High Plains area of the United States over 10 millennia ago. An early cultural horizon, the Folsom, so named from the original finds at Folsom, N. Mex., falls principally within this category. The Folsom culture is typified mainly by its projectile points. How-

ever, until recently no one had found similar evidence of man's antiquity in Alaska, which is the area through which man would have passed into the interior of the continent.

The first important writing on the subject of pre-Neolithic or relatively old horizons in Alaska was briefly sketched by N. C. Nelson (1937). In a paper describing some curious flints found on the University of Alaska campus near Fairbanks, Alaska, he compared the flints with similarly unique specimens recovered by him in the Gobi Desert of Mongolia. These artifacts consist of highly specialized examples of the flint-working art, including "fluted" flint cores, polyhedral and semipolyhedral in shape, and their derived flakes. These flakes, comparatively long and narrow with parallel sides, are called lamellar flakes because of their shape. Significantly enough, identically shaped cores and flakes have been found and noted subsequently at other places in Alaska and include the writer's finds on the north slope (pl. 3).

Although Nelson did not suggest any direct connection, these flints and associated artifacts reminded him strongly of the corresponding artifacts typical of the pre-Neolithic (or Mesolithic) times in Mongolia (Rainey, 1940, p. 302). Equating Mesolithic with an age of about 8,000 years, we assume that these artifacts represent a culture in Alaska that must have been in existence between the time of the older Folsom-point bearers and the more recent prehistoric Eskimo. There seems to be evidence that this lithic material is also of pre-Athapascan Indian age in Alaska (Skarland and Giddings, 1948, p. 116). Collins (1943, p. 233) says that "the earliest known stages of Eskimo culture are hardly more than 2,000 years old." An interesting problem of cultural connection is posed between the immediate ancestors of the Eskimos, who may have lived near Lake Baikal (Collins, 1943, p. 232), and the polyhedral-core and lamellar-flake people, who had evidently also lived in the vicinity of that same part of Siberia (Rainey, 1940, pp. 302-304). These two cultures seem to have been contemporaneous there.

It was early suggested that one of the migration routes of Early Man was probably over the unglaciated northern slope of Alaska, fronting on the Arctic Ocean. This presented, then, one of the more intriguing problem areas. Archeological investigations had been limited heretofore to only the coastal fringe, which was reasonably accessible (Larsen and Rainey, 1948, pp. 30-31). Some hints of the archeological potentialities were recorded on the north slope by Smith and Mertie (1930, pp. 110-112). These scattered finds, made by geologists of the United States Geological Survey in the early 1920's, did not seem to bespeak any antiquity, however. It was not until World War II and immediately following that there were any further archeological discoveries reported from the interior. A find

of a Folsom-type projectile point (pl. 4, *a*, insert) and some other unrelated archeological specimens were recovered by one of the United States Geological Survey parties on the Utukok River, stimulating further speculation regarding Early Man (Thompson, 1948). The Folsom-type projectile point was identified as a genuine product of Paleo-Indian workmanship by Dr. Frank H. H. Roberts, Jr., the foremost authority on Early Man in America. Here, then, was concrete evidence that our first Americans could have trekked across the northern route from Asia via an unglaciated stretch to the broad belt freed of glacial ice in the Mackenzie drainage.

The finding of the Folsom projectile point in the foothills of northwestern Alaska sheds an interesting sidelight on the probable migration path of Early Man. First, however, it should be brought to attention that, incident to the finding of the point, a total of 17 archeological sites were recorded for that same exploration party (Thompson, 1948). This was a good score for scientists pressed with geological duties. The writer, from his own research and experience, concurs with Thompson (*ibid.*, p. 62) in the latter's belief that "most of these sites are of Eskimo origin and are probably recent."

The Mackenzie River route, the first through route opened, is thought to have been freed of ice about 25,000 to 30,000 years ago. The alternate route over the divide from the Yukon drainage to the Mackenzie may not have been open until considerably later, perhaps 10,000 or more years ago (Johnston, 1933, pp. 44-45). In any event, we are assured on the basis of geological estimates that Paleo-Indians lived and hunted the now extinct mammals, principally herbivores, in the High Plains of the American Continent at least 10,000 years ago (Roberts, 1945, p. 428).

Skarland (*n. d.*, pp. 139-140) is convinced that a big-game hunter would have a better chance of survival in the unglaciated parts of Alaska during the last glacial stage than in postglacial times. In presenting his viewpoint, Skarland notes that, in addition to all the present mammalian species, the late Pleistocene fauna consisted of mammoth, bison, horse, musk ox, and, perhaps, mastodon. The caribou, still surviving to the present day, the horse, and particularly the bison would have provided most of the food. To the writer's knowledge, there is no evidence, so far, of human cultural remains found in association with the extinct mammalian remains on the Arctic slope. There were plenty of caribou bones found among the debris heaps of the prehistoric Eskimos.

In the apparent absence of Folsom-type projectile points from Siberia, it might be claimed that these objects are the products of an indigenous American technique derived from some as yet unknown prototype. However, the Utukok River point, plus the finds of J.

Louis Giddings, Jr., at Cape Denbigh on Norton Sound, which is so close to the Asiatic Continent, indicate that these particular artifacts are not very likely to have been American monopolies. Giddings (1949), in excavating a stratified site on the north Bering Sea coast, uncovered a highly significant assemblage of flint artifacts at the bottom of a stratified deposit. These artifacts were found in a layer separated from overlying later cultural remains by a layer of sterile, sandy clay. Subsequently, more recent finds of Giddings² revealed the presence of burins—the first ever reported from anywhere in the New World—associated with fragmentary Folsom and Yumalike projectile points. The chipping on the flints is finely executed. These finds represent a totally new complex of artifact associations in the prehistory of America and furnish a stepping stone in Ancient Man's trail from Asia to America.

Knowing that the United States Geological Survey intended making further explorations and surveys on the drainages bordering the area where the Folsom point was found, it seemed probable that if an archeologist were sent along on such an expedition, more evidence of Early Man might be recovered. Accordingly, after cooperation was effected between representatives of interested Government agencies, including Dr. Frank H. H. Roberts, Jr., of the Bureau of American Ethnology, Dr. John C. Reed, of the United States Geological Survey, and Dr. M. C. Shelesnyak, formerly of the Office of Naval Research, I was attached to a party of field geologists who were to examine that region during the summer of 1949.

The work of this group, party No. 6, led by Robert M. Chapman, was coordinated in a comprehensive program of systematic exploration and fact-finding research of the Geological Survey (Reed, 1949, p. 178). The area assigned to this party was in the Kukpowruk and Kokolik River drainages, adjacent to the Utukok River, near which the Folsom artifact was recovered (fig. 1). These drainages are on the western border of the area set aside by the United States Government as Naval Petroleum Reserve No. 4.

The members of party No. 6,³ with whom the writer traveled, helped immeasurably with the reconnaissance, showing a keen interest in the archeology.

The archeological reconnaissance was paced at the same rate at which the geological survey of the area was conducted, which, for the shortness of the field season of about 3½ months, was necessarily a rapid one. Operating from base camps set up along the river, the writer tried to reach a maximum number of points within a range of a day's walking distance.

² Reported at the forty-eighth annual meeting of the American Anthropological Association, New York November 17, 1949.

³ Robert M. Chapman, Edward G. Sable, Dale Hauck, Gordon Herreid, and Paul Shannon.

Recorded for the summer's work are 225 archeological and ethnological sites, plus 8 isolated features:

Archeological sites:

2 designated as "Mesolithic" on which the writer found polyhedral cores and lamellar flakes.

3 hunting camp sites.

1 possible village site on the coast near Point Lay.

2 historic-contact village sites.

184 lookout stations where flint chips occurred.

Ethnological sites:

33 recent Eskimo hunting camps.

Isolated features:

4 hunting blinds or windbreaks erected of stone.

4 stone deadfall animal traps.

Most of the lookout stations or chipping stations were situated strategically on bluffs or prominent knobs having a good view of the surrounding country (pl. 2). These stations, including the "Mesolithic" or Mongolian core sites, were at all times situated within striking distance of caribou trails, and well located at the junctions of watercourses, near passes, on ridges and hills affording unrestricted visibility for fairly long distances. Presumably these were the places where the hunters lay in wait for the caribou. Like their predecessors in this region, the prehistoric and historic Eskimos appear to have frequented the same sites and followed the same practices. The all-important man was the lookout. When he sighted the prey and gave the game signal, whole encampments of hunters dropped their tasks and hurried to the chase (Stoney, 1899, pp. 813, 817).

Indicating that the region is not quite a mammal-less desert today, our party observed several thousand barren-ground caribou moving in large herds on their migratory journeys, over a dozen bears, about 20 wolves and foxes, and a few moose. Naturally there were numerous smaller animals seen, such as marmots, ground squirrels, and lemmings.

At Umiat, I took advantage of an opportunity to brief members of five other Survey parties on the collecting and noting of archeological remains which the parties might encounter during their reconnaissances. At the close of the season, these geologists presented data on a total of 41 archeological and recent Eskimo sites. Included is material noted on previous surveys of the north slope. To this figure should be added one additional archeological site discovered by me near Umiat (Solecki, 1950a). This supplemental information gives us quite significant data, limited as it is, concerning historic and recent Eskimo camp sites on 15 of the inland rivers and 4 of the larger inland lakes.

I found no stratified sites in the course of my survey. Many of the artifacts, even some of the "Mongolian" type polyhedral cores and lamellar flakes were found practically on the bare rocks of the hills. What little soil accumulation was present on the hill summits could be called mere rock detritus. The artifacts found on the uplands were on denuded areas of what amounted to bare outcrops of sandstone and siltstone geologically dated as upper Cretaceous. These areas had scant vegetation, forsaken even by the tundra grasses in which the valleys and flats abounded. The slight precipitation provided very little erosion or soil formation; consequently the majority of the cultural remains lay practically where they had been dropped. The frigidity of the climate over a greater part of the year also accounted for the very slight soil disturbance. Therefore, beyond an occasional few inches of soil cover, there was no great accumulation of silt or soil deposits, such as are usually pointed out as an indication of stratigraphic age. Pedologists or soil scientists would call this Arctic upland very young. Telltale surface debris, commonly consisting of glistening flint flakes and other similar workshop remains, littered the small areas where the hunter probably whiled away his time patiently waiting for a sight of game.

Native stone materials for the manufacture of chipped-flint implements occurred in the form of local river cobbles and in outcrops of cherty rock. The characteristic colors of the flint were various shades of gray and green, with some reddish and black, in that order. The Lisburne limestone deposits in the mountains yielded a good supply of native chert.

The foothills area of the north slope was found to be best suited for archeological research. Indeed, by far the majority of the sites were located within the confines of this strip. It was apparently no accident that this area was favored by hunters, since even in historic times the inland Eskimos kept close to the mountains over the great part of the year (Stoney, 1899). Upon a little observation it was seen that herds of caribou could have been more easily spotted, ambushed, and dispatched with short-range weapons from the shelter of the hills than on the coastal plain. Archeologically, also, there were more exposed areas which could be readily examined in the foothills. This contrasted with the flatter coastal plain, where there were fewer denuded and barren points and consequently fewer sites to be found. A few river-cut banks and some low elevations, where a particularly resistant rock formation bulged the ground surface up in a low hillock, presented the more usual opportunities for archeological examination.

In the lower parts of the valleys, were it not for the "soil boils" or minor soil upheavals through weak points in the permanently frozen ground or permafrost, no actual soil could be seen because of the tundra

cover. The excavations attempted amounted to no more than a mere scratching of the surface through about 6 inches of moist, thawed earth to the solid permafrost. A résumé of the literature reveals that this permafrost is more than just an impediment to archeological work in the Arctic (Muller, 1947). Along the hill slopes, in lieu of normal soil erosion, the majority of the soil movements are confined to phenomena which include creeping of the soil and solifluction (*ibid.*, p. 72). Solifluction is a molasseslike, slow, downslope movement of water and saturated masses of surface ground. To this may be added also a mud flow which usually has a higher content of water and moves more rapidly. Organic deposition of matter is extremely deficient, especially on the lookout stations, as has been intimated. There are no known volcanic deposits in this region; hence there is no deposition of soil by volcanic means.

The mountains are quite rugged, and the only places suitable for archeological research are near the streams and passes of the valleys. Although limestone deposits are known in the mountains, surprisingly enough no solution caverns and only a few small "joint" caves, affording shelter, were observed in the Brooks Range by Arthur Bowsher, geologist of the United States National Museum. These mountains were thought to have been impassable during the Pleistocene, since the valleys, at least, are presumed to have been covered with ice at that time. Therefore, although evidence of later archeological material may be found in the passes, it is presumed that any finds of man's morphological remains or artifacts older than the last glacial stage will not be made in the mountain province.

Since I had to keep on the schedule of the Survey's movements, I could not undertake a side trip to the site where the Folsom point had been found by the 1947 field party, on Folsom Point Syncline, near the Utukok River. The closest approach was some 25 miles distant. A long synclinal ridge led to the site. The Folsom Point ridge, traceable on recent Geological Survey maps, is nearly 22 miles long and is situated at an elevation about 2,000 feet above mean sea level. Edward G. Sable, a member of the party and the actual finder of the Folsom point, said that he had discovered the artifact high on the ridge top, lying on the bare soil and rocks unaccompanied by any other artifacts. He noted no chipping stations or other archeological sites in the immediate neighborhood. Therefore, it was comforting to know that this was an isolated find, and presumably little would be gained by revisiting the site. It has been suggested that the long east-west trending ridges may even have been avenues of migration (Thompson, 1948, p. 64). It is possible that they could have attracted the attention of peoples moving inland from the flatter coastal plain. The tops of the ridges are considerably easier to walk upon, since they are bare of tundra, and are rather easy landmarks to follow. Tundra, composed of lichens,

mosses, and low shrubs interspersed with pools of standing water, presents a very uneven, hummocky land surface for walking, reducing the normal rate of travel speed considerably. On occasions, when traversing a particularly long stretch of tundra, it was found that the actual walking rate was only a little better than 2 miles per hour. The pace is exceedingly variable depending upon the particular stretch of terrain covered.

My archeological discoveries on the survey of the two river drainages may be roughly segregated into three temporal horizons. Divided into phases of occupation, we may distinguish as the earliest the polyhedral flint-core and lamellar-flake phase. The second is the prehistoric Eskimo phase, and the third, the historic Western Eskimo phase. The earliest of these phases, referred to previously as "Mesolithic" and represented by the two sites on the Kukpowruk River, may be equated with the University of Alaska campus site and indirectly with the finds made by Nelson in the Gobi Desert.⁴ Dr. Nelson examined the cores and flakes from the Kukpowruk River sites when the writer visited him at the American Museum of Natural History, and noted that the cores (pl. 3, *c*) recovered from one site (No. 65) are larger than the average polyhedral fluted cores.

In order to evaluate properly the polyhedral core-flake culture, we may weigh the data by using an approach such as the triad of Grahame Clark (1939, p. 133): (1) Typological considerations, (2) find complex, (3) geographical distributions. The total gives us a synchronic cultural picture of the archeology in a relative temporal frame of reference. In view of the fact that the fluted cores and lamellar flakes seem to be diagnostic of a separate cultural horizon, in Alaska at least, the presentation here is confined to these artifacts. Therefore for the sake of brevity and to eliminate detailed analysis of artifacts, the other accompanying lithic material from the various sites discussed is not enlarged upon. It may be noted that rubbed and polished stone implements, such as stone axes, are equally absent from this find complex, as they are from the well-established Paleo-Indian complexes. The fluted cores undoubtedly were the byproduct of the manufacture of the lamellar flakes. Uses for the latter may have been as small knives or possibly as inserts set in at the point end of a spear. They could also have been inserted in large projectile shafts.

It is not necessary to dwell on the description of the type specimens, since Nelson (1937, pp. 270-272) has already described them well. The technique of manufacture was presumably so specialized that it certainly did not have its origin in a short time span. The distribution is rather widespread over northern Eurasia and North

⁴ This is on the basis of the diagnostic lamellar flint flakes and the "fluted" or polyhedral flint cores (pl. 3)

America (de Laguna, 1947, pp. 171-172). There is even some resemblance to the cores and flakes of Mexico and the Hopewellian mound-building cultures. However, we are not sure of what such relationship implies. As a matter of interest, it seems that some students of prehistory suggest that the mound-building cultures of the eastern United States may have stemmed from Middle America. If this be true, they may have brought the core-flake technique with them. At present, to attempt to trace the lamellar flakes and cores outside of the immediate sphere of demonstrable geographic affinity would be rather difficult.

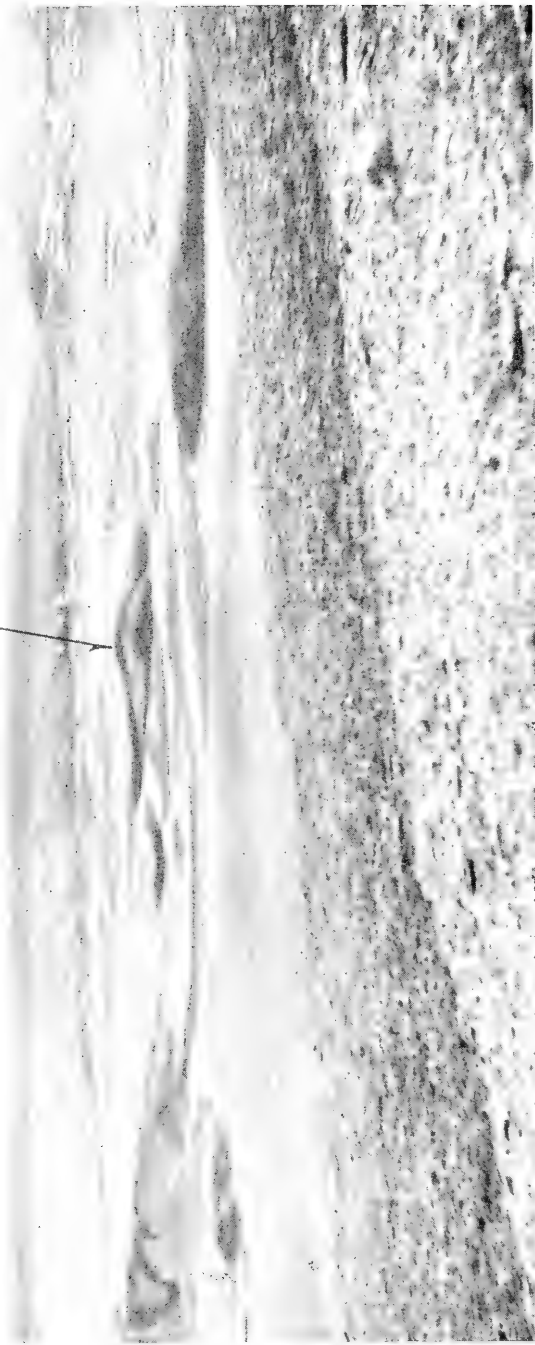
Significantly, the cores and flakes found by Johnson (1946) and Leechman (1946) in the Kluane Lake area near the Alaska Highway are roughly datable by the geology. These artifacts were found in deposits that were tentatively dated by one estimate to be about 7,000 to 9,000 years old (Leechman, 1946, pp. 387-388). This was presumably within the range of the postglacial Climatic Optimum. On the other hand, Skarland (n. d., p. 175) cites Johnson and Raup, who tentatively date their oldest Kluane Lake artifacts from about 4,000 to 5,000 years ago, or during a late phase of the postglacial Climatic Optimum. Presumably, all were speaking about the same oldest level of stratified archeological material. It is probable that Johnson's and Raup's date may be closer to the actual, at least on typological grounds. The area around Kluane Lake must have been grasslands during and after the Climatic Optimum because no trees occurred there until about A. D. 500 (de Laguna, 1949, p. 75). How recently the "Mongolian" type cores and lamellar flakes occur in northern Alaska cannot be stated definitely at present. These finds represent the work of an apparently inland population of hunters whose cultural affiliations are still not certain.

A large proportion of the sites recorded represents the next phase in our chronology which appears to be that of prehistoric inland Eskimo cultures. With the exception of several aberrant flaked artifact types, all the flint specimens appear to belong to a related culture horizon. Most of the sites were hilltop chipping or lookout stations (pl. 5, *a*). Fortunately, one of the larger hunting camps, undoubtedly a temporary base camp, was found nestled near a sheltering bluff. The cultural remains from this camp include antlers and bones of caribou cut with stone implements, antler root picks, large flint blades and scrapers, typical long, narrow Eskimo projectile points, coarse gravel-tempered pottery, some rubbed slate, a perforated bear (canine) tooth, hammerstones, and a jade adz set in an antler socket. The cultural material, with the possible exception of some of the stone blades, etc., seemed to have a lot in common with the artifactual remains of the coastal Eskimos. Caribou has been an extremely im-

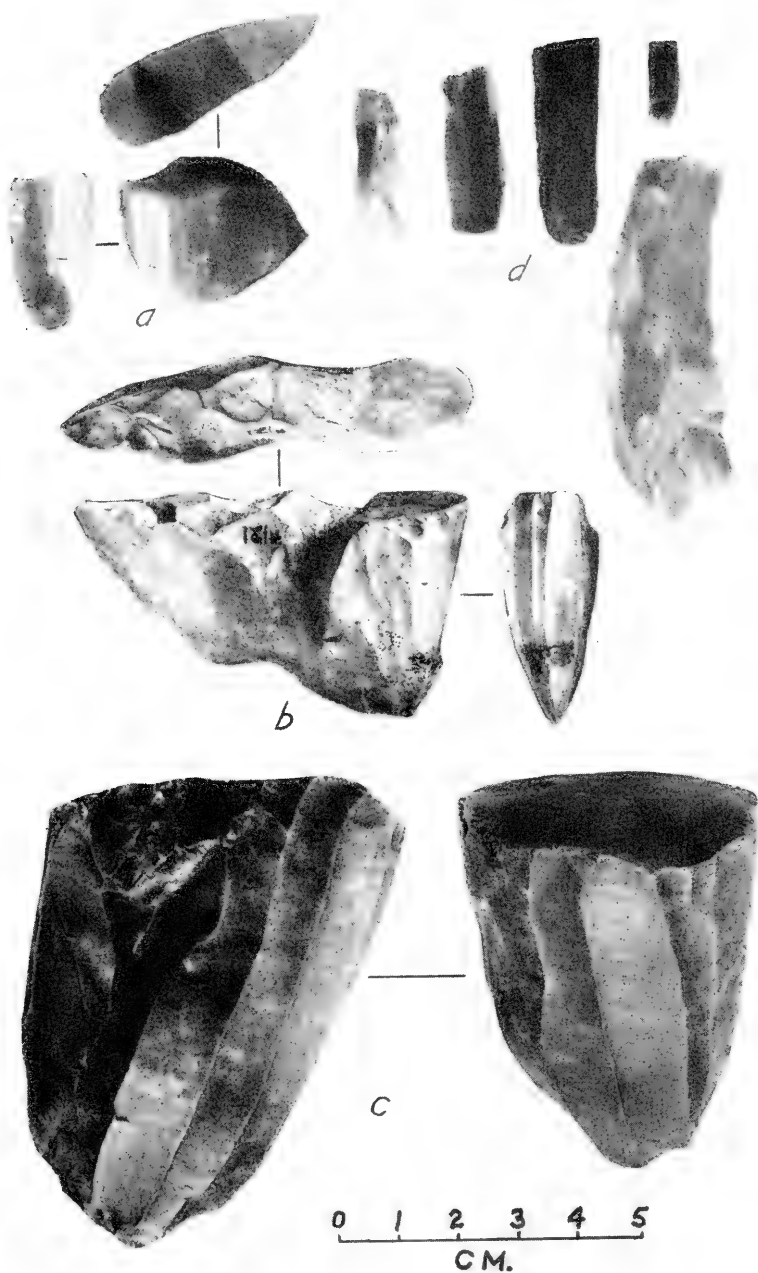


A FROST WEDGE A PHENOMENON OF PERMANENTLY OR PERENNIALY FROZEN GROUND ON THE COLVILLE RIVER NEAR UMIAT, ALASKA

SITE 65



A LOOKOUT STATION WHERE "MESOLITHIC" ARTIFACTS WERE FOUND
The area of the find is typical of the Foothills Province in northern Alaska.



LINKS BETWEEN EURASIA AND AMERICA

a and *b*, Three views each of semipolyhedral "mesolithic" flint cores; *c*, two views of a large polyhedral core; *d*, lamellar flakes. All were found on two sites on the Kukpowruk River, Alaska.



a, Edward G. Sable, of the U. S. Geological Survey, the finder of the Folsom point shown in insert, holding a mammoth tusk he recovered on the Kokolik River in Alaska; *b*, part of an encampment of the remaining inland E-skimos, the Killik tribe, at the northern end of Anaktuyuk Pass in the Brooks Range Province. (Lower photograph by George A. Llano.)



Two of several kinds of primitive housing encountered in northern Alaska.
a, A small rock-crevice shelter associated with prehistoric Eskimo artifacts on a hilltop; *b*, a recent winter sod hut erected by coastal Eskimos on the Kuk-powruk River near Point Lay.



A dome-shaped willow hut at northwestern entrance to Anaktuvuk Pass, Alaska.
a, Hut being erected. The poles in foreground were imported from south of mountain divide. A radio aerial is seen to the right. *b*, The same hut finished and covered with caribou hides. In the background are store-bought tents of other Killik Eskimos.

(Photographs by George A. Llano.)

portant source of food to the inland Eskimos, to judge from the amount of caribou-bone debris.

Although Point Hope with its rich coastal Eskimo culture, called by Larson and Rainey (1948) the Ipiutak culture, lay only about 80 miles to the west of the Kukpowruk River, no trace of recognizable Ipiutak material was discovered in the entire survey.

The third archeological phase represented on the north slope is that of the historic inland Nunatagmiut Eskimo, or the Western Inland Eskimo (Solecki, 1950a). This was also a culture dependent largely upon caribou as the main economy. The Western Inland Eskimo phase seems to have been carried on directly from the prehistoric inland Eskimo. A hunting camp found in the foothills province yielded good samples of aboriginal stone work and some historic-contact data, which ties in the prehistoric with the historic level. The people made good use of hunting blinds or windbreaks constructed of stone on the hills. There was also evidence of deadfall traps—propped-up affairs of stones that fell upon small animals when a key stick was disturbed. One small village of eight houses was found on a riverside terrace about 35 miles inland from the coast, containing much evidence of historic contact material. The houses, represented by small rectangular enclosures of turf, measuring on the average about 9 by 14 feet, had a short side entrance to the south and a central fireplace lined with stone slabs. None of the houses were of the deep subterranean type. Signs of ax and saw cuts were found on the timbers and caribou bones. From the bone remains it seems that every part of the caribou was brought to camp. The antlers were neatly cut off with metal saws, and more than one caribou skull had been carefully sawed at the top, giving access to the brain case. Since it seems that the natives were in the habit of consuming the whole animal, it is likely that the brains were also utilized. Sled runners of whalebone were found—items thus far lacking in the prehistoric culture of the same region.

One historic village of the coastal Eskimo type was discovered near the mouth of the Kukpowruk River. This village, containing 29 structural features, was of late date, possibly as recent as 50 years ago, judged from the kind of historic-contact goods present. There were 19 houses ranged along the river bank with sunken entrance tunnels. The central fireplace was absent. All the bones and antlers of caribou were metal-saw cut, and the skulls were neatly uncapped. Whale vertebrae were found on the surface of the site. One item that seemed to be out of place was an old sewing-machine head. Evidence pointing to the fact that these departed people had not forgotten their stoneworking industry was attested by the finding of flint chips on the

floor of one of the houses. There was also a small pile of common flint chips in the sod of the village area.

The coastal Eskimos living today at Point Lay venture inland to hunt caribou and to mine coal from the seams on the Kukpowruk River. The coal is put up in sacks for their own use, and transported by boats down the river. One of their sod huts (pl. 5, *b*) was found near a large riverside coal seam inland.

Unfortunately ethnological and physical anthropological data on the living Eskimos from the interior of the north slope are very meager and available to us only in accounts of late nineteenth- and early twentieth-century explorers. As far as we know, there is only one band of truly inland north-slope natives left (pl. 4, *b*). This band, called the Killik Eskimo, numbered about 60 persons at last report.⁵ They live around Chandler Lake and Anaktuvuk Pass in the mountains, with a trading station at Bettles to the south through Anaktuvuk Pass. Presumably it is to the Killiks that we owe the indications of comparatively recent camp sites in the neighborhood of the upper Colville River and its tributaries (Solecki, 1950a). Although these Eskimos still forage, living a nomadic existence, they are not without communication with the outside world. They take advantage of light plane carrier service, possess portable radios, and, according to all reports, are well versed in things mechanical, even the mysteries of repairing an obstinate outboard motor or an airplane pontoon float.

The immediate antecedents of the Killiks, probably the same people who left the historic archeological material along the rivers, were collectively known as the Nunatagmiut Eskimos. This population, which Larsen and Rainey call the Nunatarmiuts, numbered "not less than 3,000" at the turn of the century (Larsen and Rainey, 1948, p. 31). The Nunatagmiut people, according to the first-hand observations of Stoney (1899) were slow in moving over the country, since they depended entirely on the land for food. They stopped wherever they encountered herds of caribou. Even when going down river to the coast from the mountains in the springtime, only a few boats journeyed together, since enough food could not be provided for all the people at the same time. In at least one case, the Eskimos at the upper part of a river waited for the caribou to precede them downstream, so that they would have game as they descended the river (*ibid.*, pp. 813-814). Illustrative of the importance of the caribou in the inland Eskimos' economy is an inventory of the items made from, and the uses of, the various parts of these animals. The skin furnished material for huts, tents, boats, clothing, bedding, and rope;

⁵ Personal communication from Robert Rausch, U. S. Public Health Service, November 20, 1950. Mr. Rausch asserts that these Eskimo call themselves Nunamiut, a contractual name for Nunatagmiut (see below).

the sinew, thread; the antlers, such items as sinkers and tool handles; the hoofs, small boxes. The hair, mixed with tobacco, was smoked as a powerful stimulant. The bones, crushed and boiled, yielded oil. The marrow provided grease and hair oil. From the contents of the stomach a soup was made, and the flesh was eaten raw, roasted, or boiled (*ibid.*, pp. 842-843). Skarland (n. d., p. 152) estimates that an inland Arctic slope family of six persons "need a minimum of 70 caribou a year to supply the necessities." Supplementing the main diet were the less numerous and smaller game. These included bears, mountain sheep, ducks, geese, ptarmigans, and other Arctic birds and fish. In some parts, moose, marmots, and ground squirrels were available. Naturally nothing was cultivated for food owing to the harsh climatic conditions and because the natives were almost constantly moving. However, they found some products of the soil edible, thus supplementing a diet of meat. These products were principally roots, buds, and berries, eaten raw or prepared in different ways. Most of the roots were strung and boiled before eating, although they were also sometimes eaten raw. Berries were eaten before a meal and constituted a course. Stoney (1899, p. 844) said that the natives once lived on them exclusively for 5 days, but only through necessity. One dietary habit, which may seem strange to us, was the eating of white clay. It was taken only when these inland Eskimos were short of food. Stoney stated that the clay when mixed with oil, berries, and leaves, was tasteless and easy to swallow.

The houses of these historic people were built warmly and snugly enough to withstand the rigors of winter, yet they were easy to erect. They were made of plaited willows in a dome shape, held upright by a few posts (pl. 6, *a*, *b*). A layer of snow was packed over a covering of turf and moss. Another basically similar type of temporary lodging was covered with skins and then insulated with a packing of snow. When moving, the framework and skins were taken down from the inside, leaving a hollow shell of solidified snow. No mention was made of the snow-block type of house or igloo.

Physically, these inland people differed from the coastal Eskimos in several distinguishable respects, most notably in their greater height (Solecki, 1950a, pp. 140-141). There are material traits in their culture, such as the dome-shaped skin hut, which may indicate borrowing and also probably admixture with the Athapascan Indians on the other side of the Brooks Range.

SUMMARY AND DISCUSSION

All three cultures discussed, plus the Folsom-point people, had one economic trait in common. They were all hunters of herbivores—grass-eating and foraging mammals. Land-mammal hunting was

certainly an inland continental trait, requiring the mutual cooperation of the hunters. Lacking equipment other than their short-range weapons, they undoubtedly had to rely upon stealth and various means of trapping, in order to despatch their prey at close range. Whole families generally accompanied the hunt. This was not merely a trek into the game country, since these nomads lived off the land and depended for their subsistence upon the presence of the herds. According to Smith and Mertie, the Pleistocene fauna of Arctic Alaska included the mammoth, bison, horse, and musk ox.

Taking the cultures in order from the oldest thus far known on the north slope of Alaska, we have:

1. The hunters—Folsom men or Paleo-Indians, represented by the Folsom-point find in the Utukok River area. This area is situated on the unglaciated, low-lying north slope which leads eastward into the Mackenzie Valley, the first through route opened over 25,000 to 30,000 years ago. That these same Folsom people or Paleo-Indians hunted the now extinct mammals in the High Plains of the American Continent is borne out by the paleontological evidence.

In order to account for the presence of geologically dated Early Man in the High Plains of America 10,000 or more years ago, we must give priority to the north slope-Mackenzie route of migration over the Yukon drainage route. The Yukon route was opened at an estimated minimum of perhaps 20,000 to 15,000 years later.

From the premise of animal ecology, we may presume that the north slope was covered with a plant growth favorable to certain grazing mammals. Such a plant covering would extend around the low border of the Arctic Ocean and up the Mackenzie Valley along the low level region, much like the extension of the grassland today. Mammals migrating from Asia and finding suitable fodder in quantity to supply their needs, probably widened their range to correspond with the extension of plant life. Following the mammals, came man. Suitable climatic conditions were undoubtedly the forerunner of this chainlike reaction. If Early Man had made any settlements along the shores of the Arctic Ocean during the time when the glaciers locked up much of the sea water, it is unlikely that we should ever find these sites. The waters, freed by the glacial recession, would have covered the ancient shore line. Notwithstanding this, there is a strong possibility that Early Man could have hunted sea mammals in the Arctic. Giddings' recent finds at the exceptional Cape Denbigh site has revealed probable stone harpoon blades in the deepest and oldest horizon.

2. The polyhedral-core and lamellar-flake people of Alaska, come next in order and, judging by their site locales and equipment, were also hunters of the grass-eating herbivores. The culture of these

people seems to have been pre-Eskimo and pre-Athapaskan Indian. The north-slope finds may be as much as 5,000 years old. Since the cores and flakes were found on strategic hills, it indicated that these stations were used by hunters who kept a long-range lookout for herds of game. We are not certain whether bison, musk ox, moose, or caribou was the most abundant game hunted. It could have been any one of these. Today the first two of this group are extinct in Alaska, and the caribou are more numerous than moose on the north slope. Probably the climate had a disturbing effect on the ecological habitat of the bison and moose, at least. They seem to prefer different herbaceous plants than the tundra grasses upon which the cold-loving caribou thrive. This would explain why the moose and bison, by and large, migrated to warmer fields which would be more suited to the growth of plants upon which they fed. Indeed, we are told that a botanist, Hugh M. Raup, of Harvard University, finds that muskeg land or the tundra, prior to the presence of the grasslands, extended into the Peace River area of Alberta up to 2 or 3 thousand years ago. The present-day bison and moose in this region were preceded by herds of caribou (Jenness, 1940, p. 3). Raup (1941, pp. 225-227) has pointed out that attempts to correlate changing climates and vegetations on the one hand, and the migrations of aboriginal populations on the other, present some fascinating problems.

With the possible exception of some evidence found at Disco Bay, Greenland, this core-flake cultural horizon seems to have consisted primarily of inland-dwelling aborigines.

3. The prehistoric Eskimo of the third phase considered were also inland dwellers, at least for a greater part of the year. They seem to have been almost entirely dependent upon caribou as their main source of meat. Whether they descended the rivers regularly late in spring, as did the historic Eskimo described by Stoney (1899), we do not know. However, in all likelihood they did, as evidenced by the presence of aboriginal trade goods found at the sites. All the lithic material recovered seems to have been locally derived.

A United States naval officer and explorer, Lt. George M. Stoney (1899), has offered us the best graphic eyewitness account of the inland Arctic people, the Nunatagmiut. Larsen and Rainey (1948, pp. 30-36) summarize our knowledge of the inland Eskimos from various sources. One of the most pertinent remarks about the Nunatagmiut made by the latter authors (*ibid.*, p. 31) is that "above all, it is their ecology which makes these inland Eskimos a unit and serves to distinguish them from the coast Eskimo." Outright starvation and disease, particularly diseases introduced by the white man, accounted for the decimation of the Nunatagmiut at the turn of the nineteenth century.

The reason why the inland Eskimos occupied this environmental niche in the Arctic seems to be one of choice, reaching far back into antiquity. The writer concurs with Larsen and Rainey's (1948, p. 36) opinion that the cultural difference between the coastal and inland Eskimos "is apparently deeply rooted." A summation of the archeological differences and resemblances between these two economically divergent cultures awaits analysis. The matter of geographic conditions and their impress upon the cultural scheme of a people does not seem resolvable in terms other than those involving the interaction of organism and environment. Pursuant to our theme, Sauer (1944, p. 529) remarked, "A given environment offers a determinable range of options to a given cultural group, but this range, for the same area, may be quite different for another culture." In other words, as Fredrik Barth (1950, p. 338) has said, "It is . . . possible for a group of people to exploit only a small part of the total available food source, as clam diggers or deer hunters, who may be as limited and specialized in their food habits as are most mammalian species." But the given environment here, the inland Arctic, is one of the last places in the world to find anything resembling a wide range of options for habitation. This is one of the areas of marginal cultural survival, whose occupants were perforce dependent almost wholly upon herbivorous mammals in their hunting-foraging existence. In fact, the natives in late prehistoric and historic times at least, were dependent to a large extent upon a single species of mammals, the caribou.

How the factors of ecological succession, an orderly set of changes from one kind of habitat to another, affected primitive man in the Arctic, we do not know at present. These changes, presumably rather slow, are continually taking place in the environment. Even slight differences in climate may have broadly reaching effects in the vegetation of a habitat. This in turn may influence the animal life. Man might survive the situation, or depart. Elton (1939, p. 156) makes a highly suggestive statement: "It seems highly probable, although difficult in the present state of our knowledge to prove conclusively, that many animals migrate on a large scale in order to *get away from* a particular place rather than to *go towards* anywhere in particular."

It is difficult to appraise the societal basis of the bands of inland Eskimos in the manner described for other cultures by Julian Steward (1936), because the people are gone, and with them, the needed information. Certainly inferences can be made, but these cannot be substituted for facts. We may still be able to extract some ethnological data from the present-day Killiks, who are supposedly the descendants of the original Nunatagmiuts. Some information may be obtained relevant to the social problems of these people from the bands of inland Eskimos still living on the south side of the Brooks Range.

CONCLUSIONS

We have briefly explored the relationship of archeology to ecology on the northern slope of Arctic Alaska. The total of the archeological sites recorded amounted to 217, all of which, with the exception of 17 noted by Thompson (1948), were recorded by the writer (Solecki, 1950a, 1950b). This shows that the Arctic interior region is not a barren area for archeological research. The foothills area of the Brooks Range was especially prolific. There were 75 other occupational features—recent Eskimo hunting sites and other isolated man-made works, such as windbreaks and stone traps. Evidence seems to point to the fact that this region was on the migratory route of Early Man or Paleo-Indian and of mammalian life from Asia into North America in glacial and postglacial times. Counting from the earliest horizons, we have at least four cultures chronologically represented on the north slope: (1) The Folsom or Paleo-Indian cultures, comparatively the oldest known; (2) the polyhedral flint-core and lamellar-flake people ("Mesolithic culture"), represented by finds on two sites; (3) a prehistoric inland culture, presumably Eskimo, which blends into the last of our series; (4) the historic inland Nunatagmiut Eskimos. There is only one small band of inland north-slope Eskimos left. These are the Killiks, who are faced with possible extinction.

In following the archeology through a time depth in the inland Arctic, we thread through the ecological environment of the region, embracing related aspects of biological and earth sciences. Considered from an archeological angle, any ecological study must be a dynamic one. In terms of the simplicity of habitat, the Arctic is one of the few places where it is possible to approximate a complete ecological synthesis. In order that the natives might subsist in this region, they had to be hunter-foragers, with a dependence upon herbivorous prey. The latter were dependent upon the availability of fodder suitable to them, which, in turn, depended upon climatic fluctuations.

It is hoped that the programs of future archeological research in this region will include in their scope an awareness of the various leads of ecology that we have attempted to utilize. As a problem area, its prehistory is long and challenging, and the understanding of it requires not only a knowledge of man and his works, but his relationship to animals, plants, and climate.

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SAMUEL SEYMOUR: PIONEER ARTIST OF THE PLAINS AND THE ROCKIES

By JOHN FRANCIS McDERMOTT

[With 16 plates]

Of all the artists who penetrated our frontiers in the early decades of the nineteenth century Samuel Seymour has remained the most elusive. He should have found an important place in the pictorial record of the western plains and the Upper Mississippi, for so far as we know he was the first man with any artistic skill to travel through those regions sketchbook in hand, and the first views of many famous spots were no doubt those taken by him. Other men after him, more energetic in pushing their fortunes or more fortunate in the preservation of their pictures, achieved considerable repute and left behind them masses of identifiable work, whereas Seymour has been neglected and almost forgotten. James Otto Lewis, who painted Indians in Wisconsin and Minnesota in 1824-26, became well known through his "Aboriginal Port Folio," published in 1835-36. George Catlin, who did not ascend the Missouri until more than a decade after Seymour, in later years won much publicity by his skillful showmanship; through his traveling gallery and his books he preserved for the future a vast number of his subjects. Bodmer's record of the Missouri and its Indians, done in 1833, saw extensive publication in the Atlas to Prince Maximilian's "Travels in North America," first printed in German in 1839-41, but very soon issued also in Paris and London editions. Alfred J. Miller may not have made any great impression on his time by his water colors of Sir William Drummond Stewart's sporting expedition to the Rocky Mountains in 1837, but the sketches were preserved so that Miller is now represented by the most complete series of pictures of one expedition known to exist today. The Kern brothers in the 1840's and 1850's saw much of their work lithographed in official publications of the records of the exploring parties they accompanied. Even Father Nicholas Point, companion of De Smet and strictly an amateur, though still largely unpublished, can yet offer us several hundred sketches of western scenes in the 1840's. Only Seymour, the first of them all, is sparsely represented in our files today. The importance of Seymour is that he was the first artist to fill his portfolio with sketches of scenery on the Missouri, the Platte, the

Arkansas, on the Great Plains, and at the foothills of the Rockies, as well as on the Upper Mississippi, the Red River of the North, Lake Winnipeg, and Lake Superior. His misfortune lies in his elusiveness, in the disappearance of the great part of that large body of work he accomplished on those two early journeys beyond the frontier.

Little is known of Seymour's early years. Dunlap, in his "History of the Arts of Design," said he was a native of England and a friend of Thomas Birch, John Wesley Jarvis, and Thomas Sully in Philadelphia (Dunlap, 1918, vol. 3, pp. 26, 257). At least three pictures by Birch were engraved by Seymour: Philadelphia (with the Treaty Elm) published May 1, 1801; New York (the "View with the White Horse") issued January 1, 1803; and Mount Vernon, March 15, 1804 (Stokes and Haskell, 1933, pp. 46, 48). About 1815 there was published an engraving by Steel of a Seymour drawing of the Battle of New Orleans (Stauffer, 1907, vol. 2, p. 500). A primitive oil on canvas of "Indians, Salmon Falls [New Hampshire]," owned by the Whitney Museum of American Art, is supposed to be the work of Seymour (pl. 1).¹ Only for the years 1819-23, however, is there any appreciable information about his work.

Seymour's opportunity came when Maj. Stephen H. Long was organizing the Yellowstone Expedition. The desirability of a staff artist was clearly felt, and he was chosen for the position. The instructions given him in Major Long's orders of March 31, 1819, make clear how valuable his portfolio must have been by the time the party reached home. He was to "furnish sketches of landscapes, whenever we meet with any distinguished for their beauty and grandeur. He will also paint miniature likenesses, or portraits if required, of distinguished Indians, and exhibit groups of savages engaged in celebrating their festivals, or sitting in council, and in general illustrate any subject, that may be deemed appropriate in his art" (James, 1823, vol. 1, p. 3).

Unhappily, in Edwin James' official report of Long's western expedition, there are few references to, and little detail concerning, the day-by-day work of the artist. In a note at the close of that publication James stated that Seymour had done 150 "landscape views" of which 60 had been finished (*ibid.*, vol. 2, p. 330). But a check of the James volumes does not identify many scenes that the artist sketched. Long himself in his report to Secretary of War Calhoun said that "Mr. Seymour has taken numerous landscape views, exhibiting the characteristic features of the country, besides many others of detached scenery" (James *in* Thwaites, 1905, vol. 17, p. 181). Of all this work, however, only 16 pictures can be identified today; this lot includes not

¹ For permission to reproduce pictures by Seymour I wish to thank the Academy of Natural Sciences of Philadelphia, the Whitney Museum of Art, and the Yale University Library.

merely the illustrations of the English and American editions (which were not all the same) but also a number of unpublished water colors.

The extant Seymour illustrations for the 1819-1830 expedition are to be found in four lots:

1. Atlas to the American edition of James' "Account of an Expedition":
 - War Dance in the Interior of a Konza Lodge.
 - Oto Council.
 - Oto Encampment [pl. 5 in this paper].
 - View of the Rocky Mountains, on the Platte, 50 Miles from their Base.
 - View of the Insulated Table Lands at the Foot of the Rocky Mountains [pl. 11].
 - View of Castle Rock, on a Branch of the Arkansa, at the Base of the Rocky Mountains.
2. The English edition:
 - Distant View of the Rocky Mountains (in color), vol. 1, frontispiece.
 - War Dance in the Interior of a Konza Lodge, vol. 1, p. 126.
 - Oto Council, vol. 1, p. 140.
 - View of the Chasm through which the Platte Issues from the Rocky Mountains (in color), vol. 2, frontispiece.
 - Pawnee Council, vol. 2, p. 76.
 - Kiawa Encampment, vol. 3, frontispiece.
 - Kaskaia, Shienne Chief, Arrappaho, vol. 3, p. 48.
3. The Coe Collection, Yale University Library (original drawings):
 - War Dance in the Interior of a Konza Lodge [pl. 2].
 - Pawnee Council [pl. 4].
 - View near the Base of the Rocky Mountains [pl. 6].
 - View Parallel to the Base of the Mountains at the Head of the Platte [pl. 7].
 - Cliffs of Red Sandstone near the Rocky Mountains [pl. 8].
 - Hills of the Trap Formation [pl. 9].
 - View on the Arkansa near the Rocky Mountains [pl. 10].
 - Kiowa Encampment [pl. 12].
 - Kaskaia, Shienne Chief, Arrappaho [pl. 13].
4. Academy of Natural Sciences, Philadelphia (original drawing):
 - Oto Council [pl. 3].

Two other illustrations used in the James publications were not Seymour's original work: "Skin Lodges of the Kaskaia's" was by T. R. Peale; the "Facsimile of a Delineation upon a Buffalo Robe," of course, was merely a copy by Seymour of an Indian original (Seymour's drawing of the latter is in the Coe Collection).

Seymour joined Long's party at Pittsburgh some time in the spring of 1819. As an artist he is first mentioned by William Baldwin, physician and surgeon as well as botanist to the expedition, in a letter to his friend William Darlington. Writing from on board the steamboat *Western Engineer*, Pittsburgh, May 1, 1819, Dr. Baldwin remarked that "Mr. Seymour [had] sketched a number of romantic views" in that neighborhood (Darlington, 1843, p. 313). The official report, however, said nothing of these drawings.

The first glimpse James gives us of Seymour at work occurred at Cave-in-Rock (30 miles below the Wabash) on May 29, 1819, where the party had spent the night. "Early the next morning," the account reads, "we went to visit the cave, of the entrance to which two views were sketched by Mr. Seymour" (James, 1823, vol. 1, p. 32). On June 6, when they were below Herculeaneum on the Mississippi, T. R. Peale noted in his journal that they passed under "the most sublime bluffs of limestone rocks that I ever beheld. Nearly all of the hills on the left shore were walled with these tremendous precipices of from 1 to 300 feet perpendicular, resembling walls and towers, some with bare tops and others capped with grass and shrubbery. . . . We being obliged to go directly at the foot of these hills, were not able to take many views of them. Mr. Seymour, however, succeeded in getting one or two" (Weese, 1947, p. 158). None of these sketches can be located.

The party now proceeded to St. Louis, where they stayed 12 days. From St. Charles, Mo., Seymour set out overland with Say, Jessup, and Peale while the others continued up the Missouri by boat. During this walk across the State of Missouri, there is no mention of any sketches by Seymour. Above Fort Osage the artist found in a Kansa village a subject to be used as his first contribution to the published account. The journalist of the party made an interesting report of this episode:

Mr. Say's party were kindly received at the village they had left on the preceding day. In the evening they had retired to rest in the lodge set apart for their accommodation, when they were alarmed by a party of savages, rushing in armed with bows, arrows and lances, shouting and yelling in a most frightful manner. The gentlemen of the party had immediate recourse to their arms, but observing that some squaws, who were in the lodge, appeared unmoved, they began to suspect that no molestation to them was intended. The Indians collected around the fire in the centre of the lodge, yelling incessantly; at length their howlings assumed something of a measured tone, and they began to accompany their voices with a sort of drum and rattles. After singing for some time, one who appeared to be their leader, struck the post over the fire with his lance, and they all began to dance, keeping very exact time with the music. Each warrior had, besides his arms, and rattles made of strings of deer's hoofs, some part of the intestines of an animal inflated, and inclosing a few small stones, which produced a sound like pebbles in a gourd shell. After dancing round the fire for some time, without appearing to notice the strangers, they departed, raising the same wolfish howl, with which they had entered; but their music and their yelling continued to be heard about the village during the night. [James, 1823, vol. 1, p. 135.]

This "dog dance," we are told, had been performed for the entertainment of the guests. "Mr. Seymour took an opportunity to sketch the attitude and dresses of the principal figures (*ibid.*) (pl. 2). On publication the plate was incorrectly entitled "War Dance in the Interior of a Konza Lodge."

At Engineer Cantonment near Council Bluffs, where Long's party encamped for the winter, a council was held on October 4 at which about 100 Otos, 70 Missouris, and 50 or 60 Iowas were present. According to the record,

They arranged themselves, agreeably to their tribes, on puncheon benches, which had been prepared for them, and which described a semicircle, on the chord of which sat the whites, with Major O'Fallon and his interpreters in the centre. Sentinels walked to and fro behind the benches; and a handsome standard waved before the assembly. The council was opened by a few rounds from the howitzers. A profound silence reigned for a few minutes, when Major O'Fallon arose, and in a very animated and energetic manner addressed his Indian auditors. Suitable replies were given by Shonga-tonga, the Crenier and others, with all the extravagant gesticulation which is one of the prominent features of Indian oratory. [Ibid., vol. 1, p. 158.]

At some time during this meeting Seymour sketched his "Oto Council" (pl. 3), which was used to illustrate both editions of the narrative. Less than a week later the Pawnees came in for a talk. In the water color now made ("Pawnee Council") the artist gave a different view (pl. 4) of the council grounds and a detail more in keeping with the text quoted above than was that of the "Oto Council" (ibid., vol. 1, p. 159).

There are no further references to Seymour's delineations until the next spring or summer. The "Oto Encampment" (pl. 5.), which was published only in the American edition, may have been done in March or April during the winter encampment, or in June on the march up the Platte Valley. In it was represented "an encampment of Oto Indians, which Mr. Seymour sketched near the Platte river . . . the group of Indians on the left is intended to represent a party of Konza Indians approaching to perform the calumet dance in the Oto village . . . this party when still distant from the Otoes, had sent forward a messenger, with the offer of a prize to the first Oto that should meet them. This circumstance was productive of much bustle and activity among the warriors and young men, who eagerly mounted their horses, and exerted their utmost speed" (ibid., vol. 1, pp. 188-189).

Presently the explorers—whose new orders had diverted them from the Yellowstone objective to a round over the Great Plains to the mountains—on June 30, 1820, "were cheered by a distant view of the Rocky Mountains" (ibid., vol. 1, p. 489). Although James did not mention it, the artist must now have done the "Distant View of the Rocky Mountains" which forms one of the illustrations of the English edition. Literally, these were not the Rockies, but they were practically the beginning of the mountains. Probably a day or two later Seymour sketched the "View of the Rocky Mountains, on the Platte, 50 Miles from their Base," published in the American edition.

Next Seymour drew his "View of the Chasm through which the Platte Issues from the Rocky Mountains" (English edition only). Their camp on July 5 was "immediately in front of the chasm," the view being taken from a "commanding eminence" a little to the south of camp. (The paragraph in which this sketch is mentioned appears only in the English edition; James *in* Thwaites, 1905, vol. 15, pp. 285-286.)

Most of this month was spent in crossing the present State of Colorado from the headwaters of the Platte to the headwaters of the Arkansas. At least seven views for this portion of the trip exist. Of 10 Seymour water colors in the Coe Collection of Yale University Library (all of which must have been among the 60 pictures finished by the artist), 5 were never published. From their subjects they belong to July 1820: "View near the Base of the Rocky Mountains" (pl. 6), "View Parallel to Base of the Mountains at the Head of the Platte" (pl. 7), "Cliffs of Red Sandstone near the Rocky Mountains" (pl. 8—possibly July 6), "Hills of the Trap Formation" (pl. 9—probably July 28), and "View on the Arkansa near the Rocky Mountains" (pl. 10). These pictures are all signed either "S. S." or "S. Seymour," and the captions are in his hand.

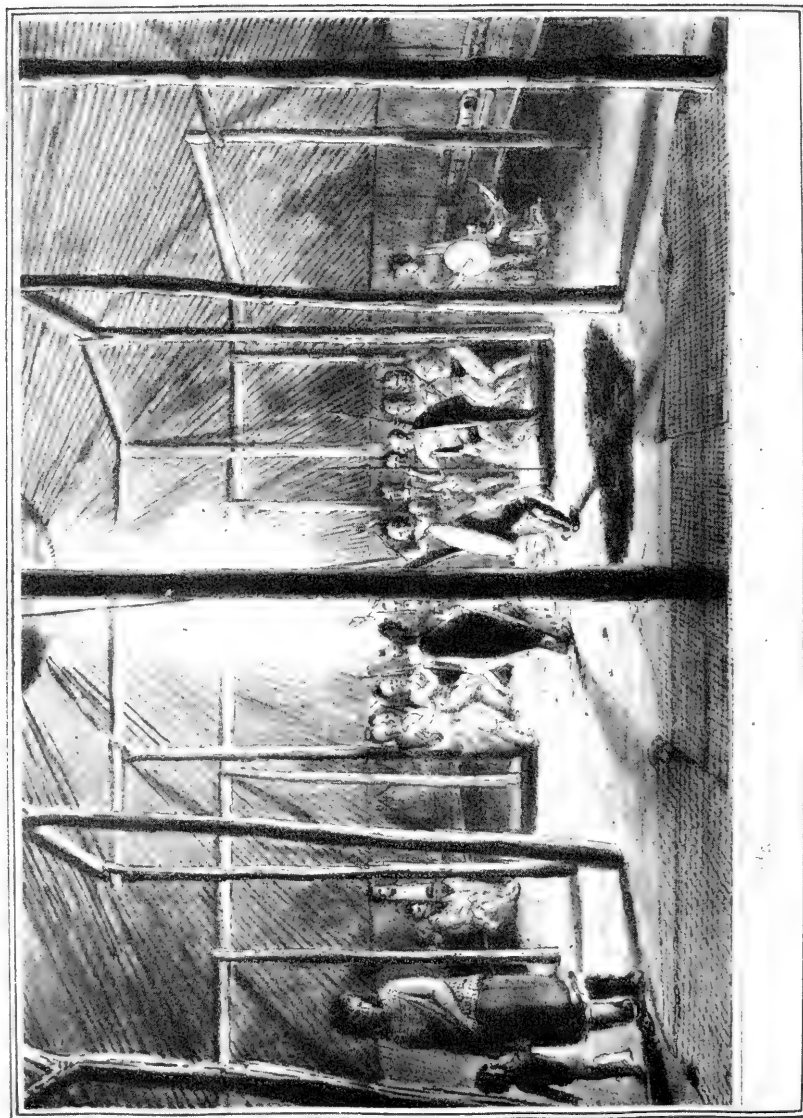
Two other pictures for this area were published in the American edition: a "View of the Insulated Table Lands at the Foot of the Rocky Mountains" (pl. 11), and a "View of Castle Rock, on a Branch of the Arkansa, at the Base of the Rocky Mountains" (James, 1823, vol. 2, p. 16). James mentioned another subject that was not reproduced. As the party moved south it came to a hill from the top of which "the High Peak mentioned by Capt. Pike" was discovered. In this neighborhood they came on "several rock formations beautifully exposed," and Seymour made sketches of "these singular rocks" (James *in* Thwaites, 1905, vol. 15, p. 302).

On July 24 a party consisting of Captain Bell, Say, Seymour, and others was detached to proceed eastward along the Arkansas. Two or three days later they came upon a Kiowa encampment, and the artist did another of his interesting views (pl. 12). The foreground pictures the tents and flagstaff of the whites, with Indians crossing the river in the middle distance, and the Indian encampment far beyond the river on the horizon. It was probably on this occasion that Seymour also made the sketches of the three Indians represented on the plate of "Kaskaia, Shienne Chief, Arrappaho" (pl. 13). (James, 1823, vol. 2, p. 175 ff.) Both of these pictures were used in the English edition.

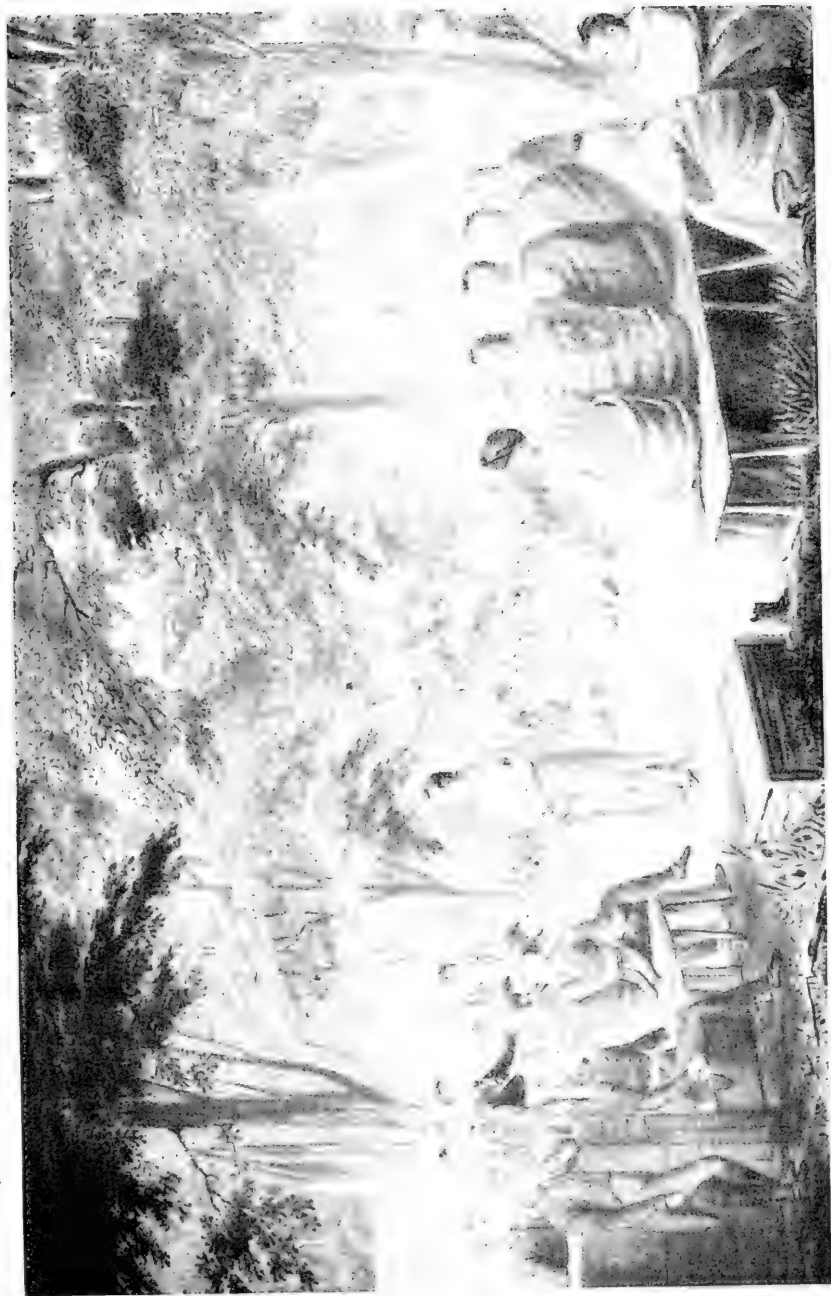
At the close of the expedition the journals and papers of the various members were placed in James' hands for the preparation of a book for the general public about the exploratory expedition, and for this Seymour was to furnish illustrations. Work progressed slowly. On



INDIANS, SALMON FALLS
Oil on canvas. Collection of Whitney Museum of American Art.



WAR (DOG) DANCE IN THE INTERIOR OF A KONZA LODGE
Water color. Coe Collection, Yale University Library.



OTO COUNCIL

Water color from the Lawson Scrapbooks. Courtesy Academy of Natural Sciences of Philadelphia.

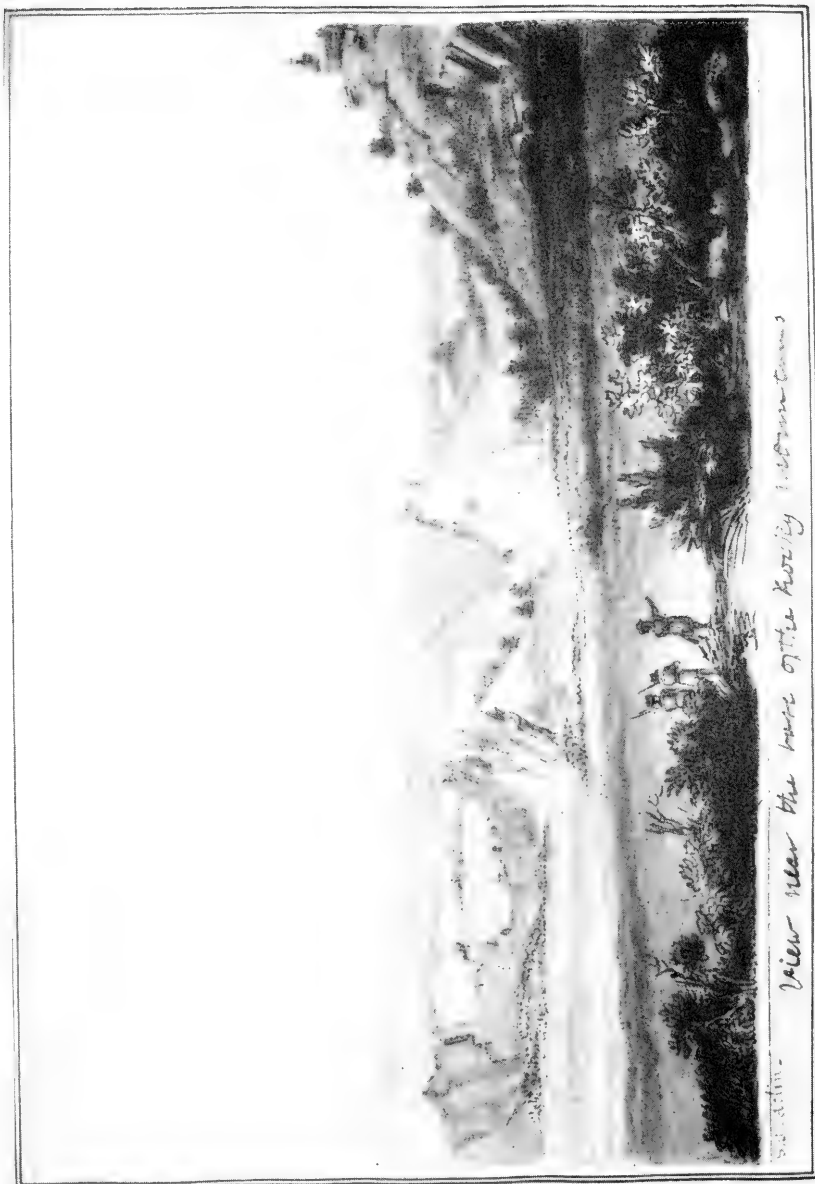


PAWNEE COUNCIL
Water color. Coe Collection, Yale University Library.

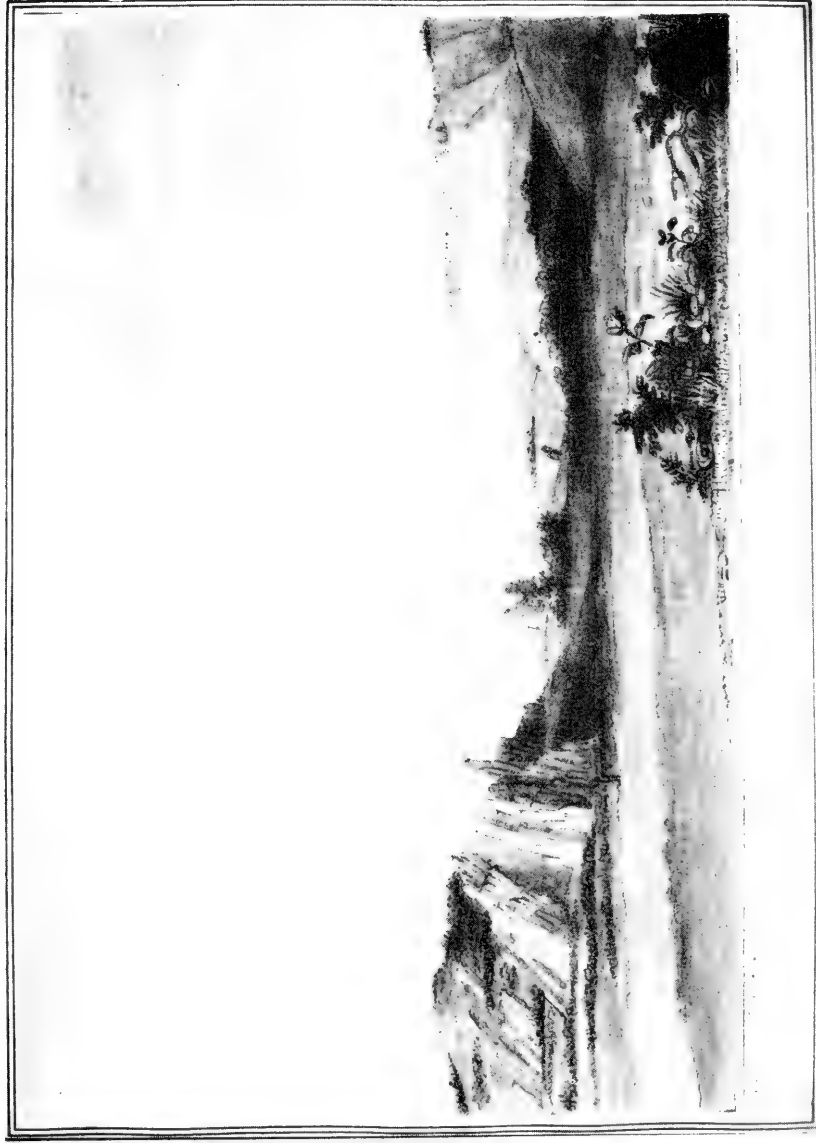


OTO ENCAMPMENT

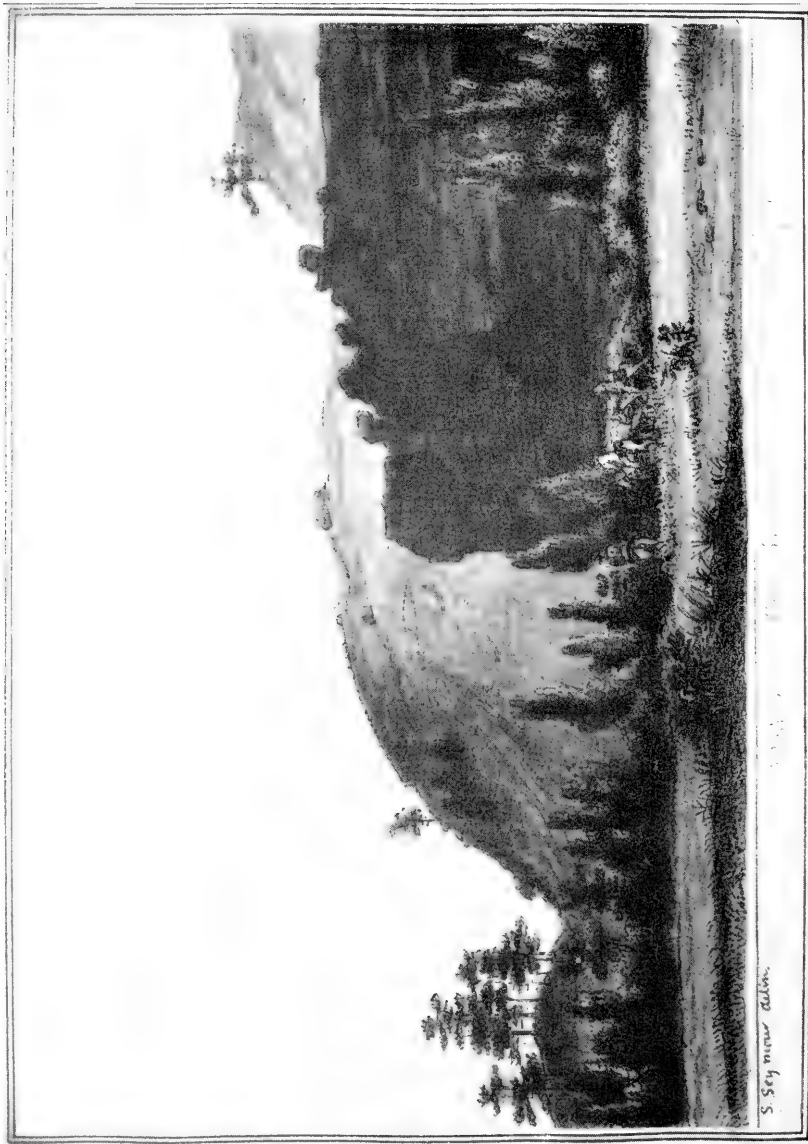
Engraved by F. Kearney. From James' "Account of an Expedition."



VIEW NEAR THE BASE OF THE ROCKY MOUNTAINS
Water color. Coe Collection, Yale University Library.

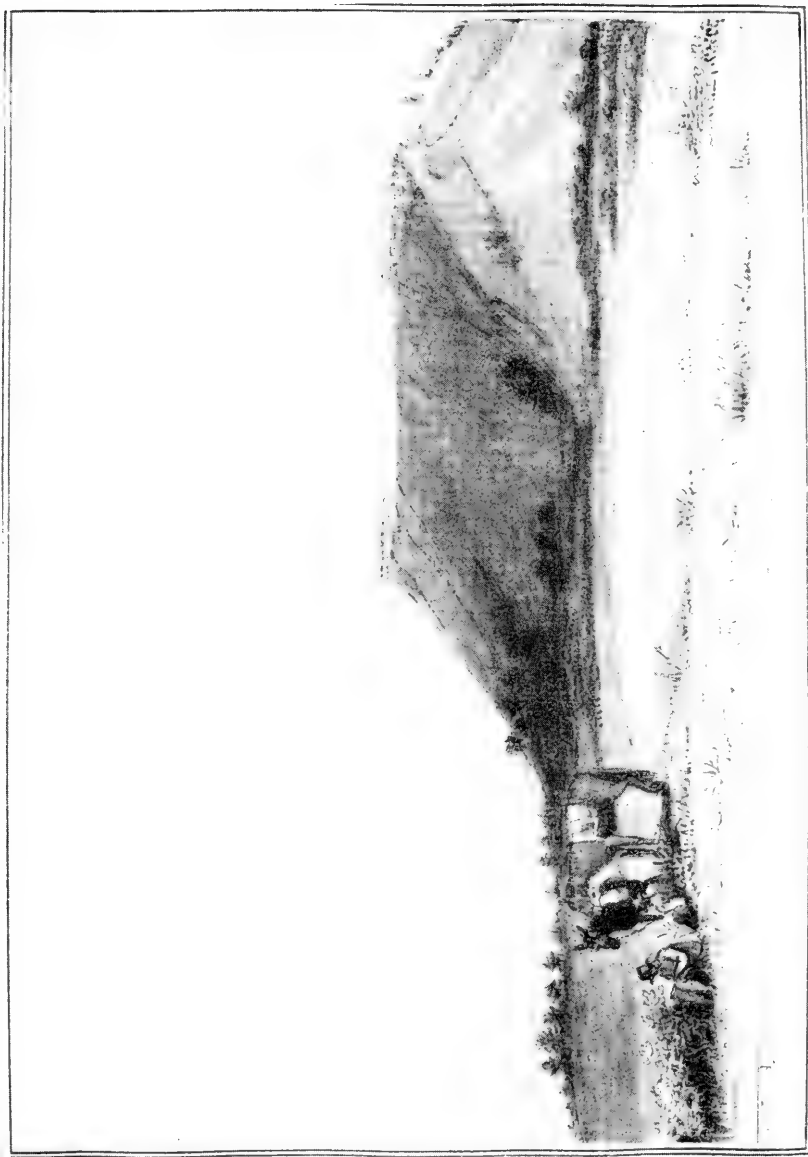


VIEW PARALLEL TO THE BASE OF THE MOUNTAINS AT THE HEAD OF THE PLATTE
Water color. Coe Collection, Yale University Library.

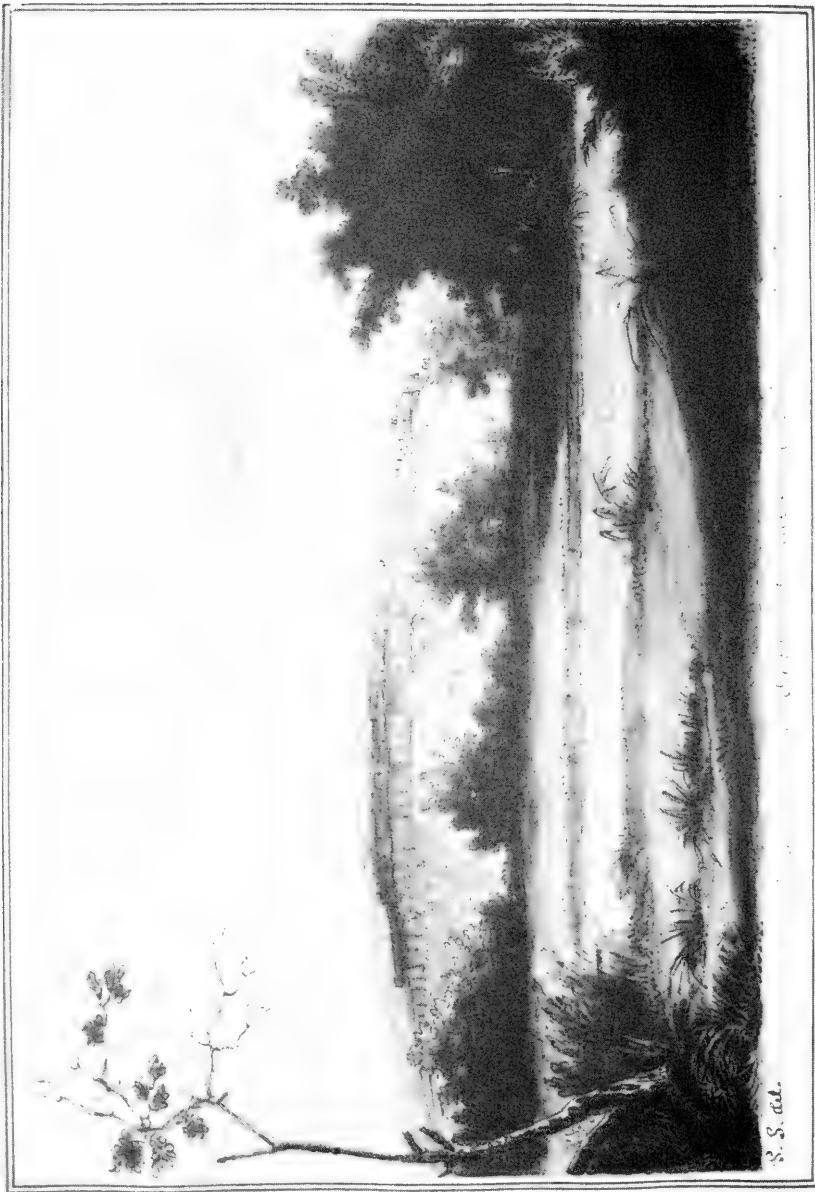


S. Stry near color.

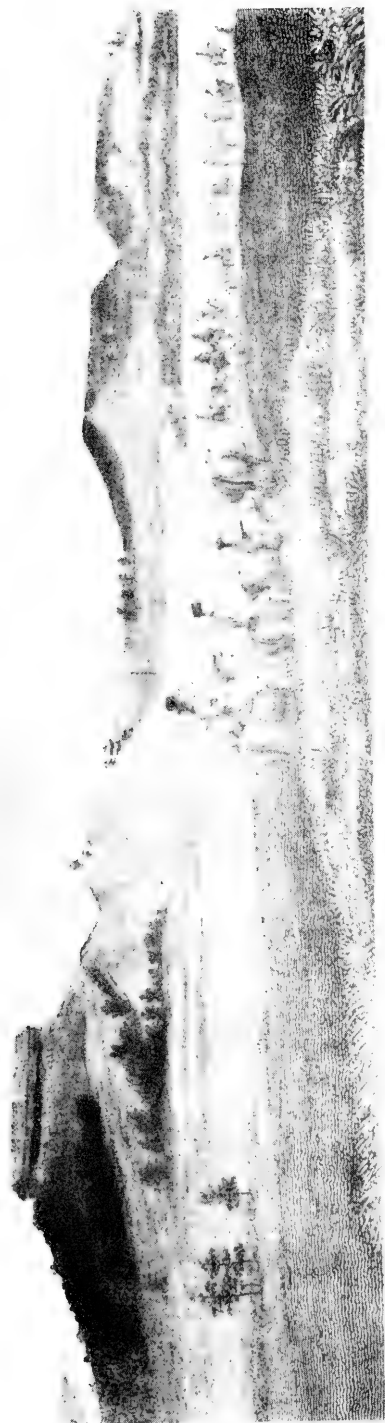
CLIFFS OF RED SANDSTONE NEAR THE ROCKY MOUNTAINS
Water color. Coe Collection, Yale University Library.



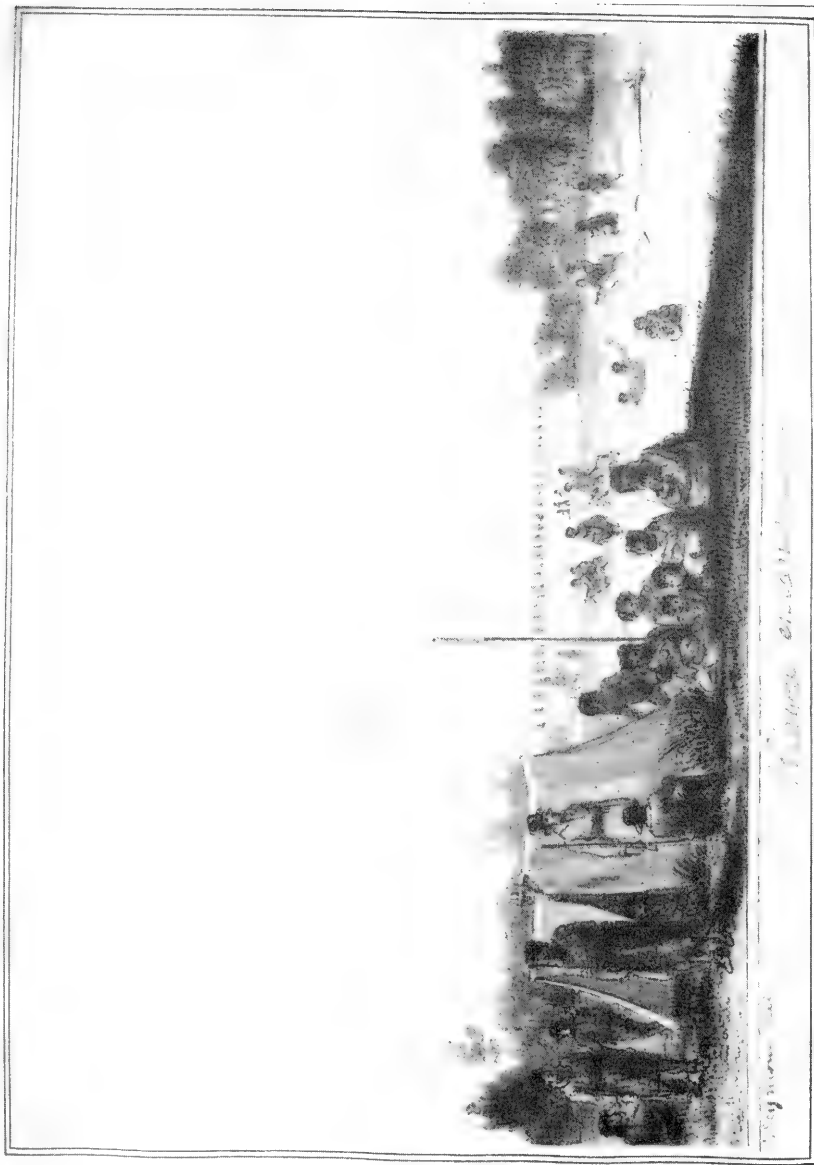
HILLS OF THE TRAP FORMATION
Water color. (Coe Collection, Yale University Library.)



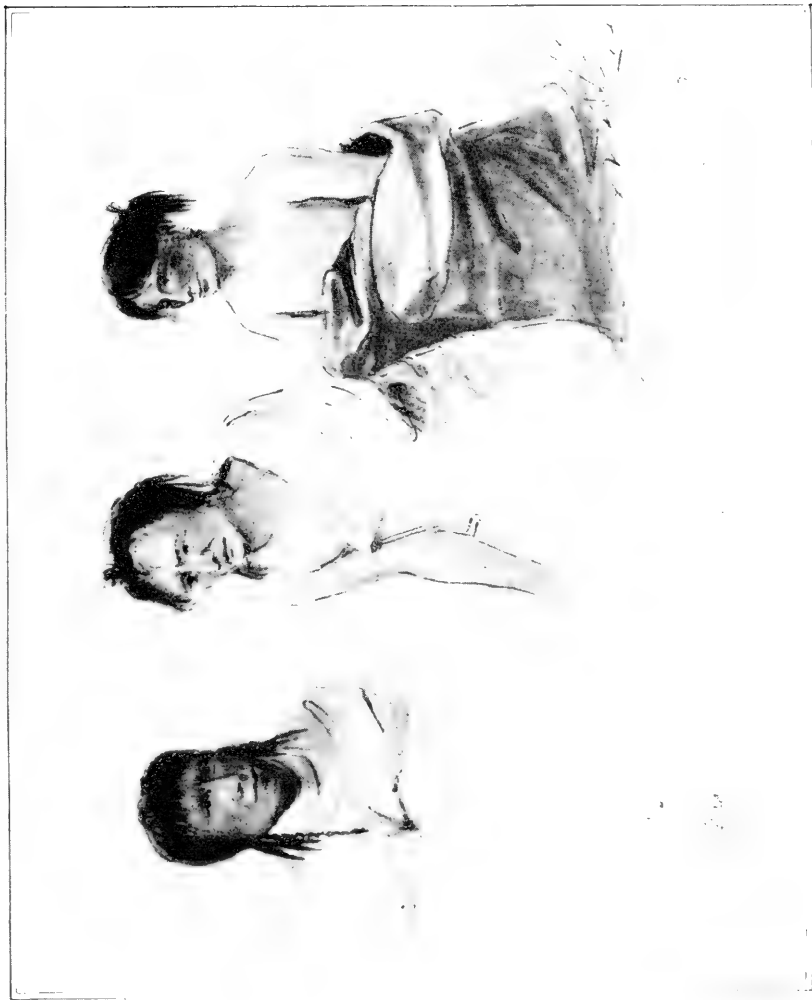
VIEW ON THE ARKANSAS NEAR THE ROCKY MOUNTAINS
Water color. Coe Collection, Yale University Library.



VIEW OF THE INSULATED TABLE LANDS AT THE FOOT OF THE ROCKY MOUNTAINS
Engraved by C. G. Childs. From James' "Account of an Expedition."



KIOWA ENCAMPMENT
Water color. Coe Collection, Yale University Library.



KASKAIA, SHIENNE CHIEF, ARRAPPAHO



Fig. 14. Maiden's Rock, Mississippi.

THE MAIDEN'S ROCK ON THE MISSISSIPPI
Engraved by J. Hill. From Keating's "Narrative."



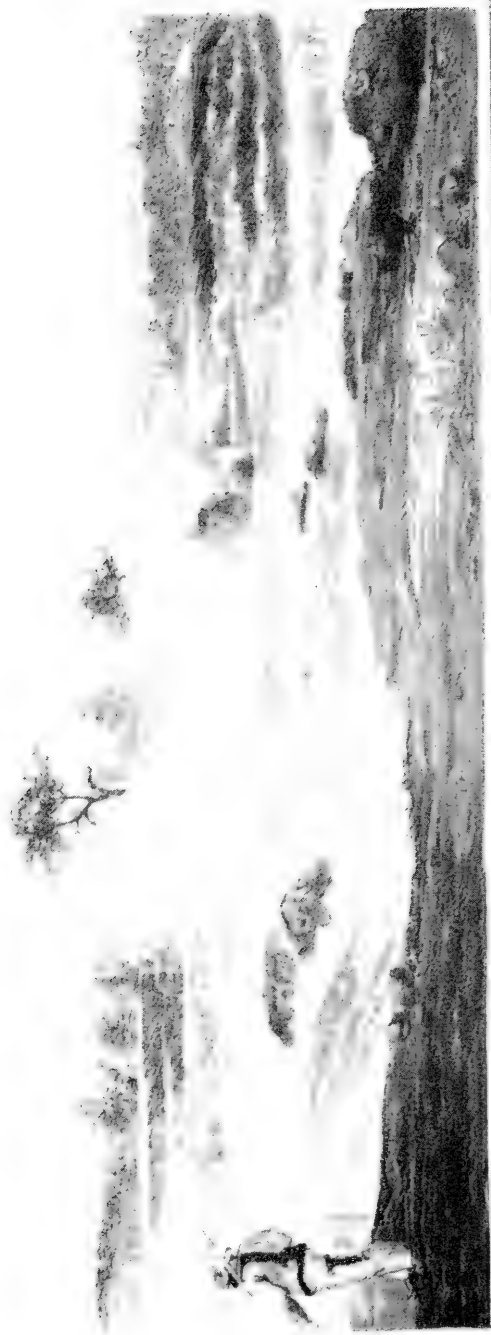
Designed by S. Seymour

Engraved by H. C. Carey & Co. 1854

Plate 15

WANOTAN AND HIS SON

Wanotan and his son
Engraved by J. Hill. From Keating's "Narrative."



Designed by N. S. S. S.

Pl. No. 1. From N. S. S. S.

Pl. No. 1. From N. S. S. S.

UPPER FALLS OF WINN^EWEEK RIVER
Engraved by J. Hill. From Keating's "Narrative."

June 10, 1822, Long wrote to Colonel Roberdeau, in charge of the Topographical Bureau of the Army, that the artist had then completed about 60 of his drawings and that 20 had been selected for the English edition. Nineteen days later in another letter to Roberdeau, Long expressed considerable exasperation with his artist: "Since writing my last, Seymour has done nothing. I cannot get him to complete the Drawings for our Book. A strange infatuation seems to have seized him—and I know not when to expect his recovery." The outcome of this affair is cloudy. Long evidently had hopes of using many pictures, but both the American and the English editions came out very sparingly illustrated. The Coe Collection views already mentioned comprise 5 of the unpublished finished pictures, but what became of more than 40 others is still a mystery.

In 1823 Long set out on the exploration of the country above Fort Snelling. Whatever had been the difficulties over the finished sketches for the James account of the western expedition, Seymour again went out as "Landskip Painter." Our knowledge of his work done on this journey is derived from William H. Keating's official "Narrative of an Expedition to the Source of the St. Peter's River, Lake Winnepeg, Lake of the Woods &c. &c. performed in the year 1823 . . . under the Command of Stephen H. Long, Major U. S. T. E." There we find 11 plates and a few references to other drawings by Seymour.

The party moved west from Philadelphia through Wheeling and Zanesville. In Piqua on the Miami they stopped for a day to examine the mounds and then proceeded to Fort Wayne. There they were interested in the Pottawatamies, and there "Mr. Seymour took a likeness of him [Metéa] which was considered a very striking one" by all who knew him. One cannot, however, offer much praise for that head as it is reproduced in plate 3 of the first volume. Keating described this chief as about 40 or 45 years old: "He has a forbidding aspect, by no means deficient in dignity; his features are strongly marked, and expressive of a haughty and tyrannical disposition . . . he is characterized by a low, aquiline, and well-shaped nose . . . his forehead is low and receding . . . His hair . . . indicates a slight tendency to curl . . ." (Keating, 1824, vol. 1, pp. 89-90). One would almost doubt that Keating and Seymour had been looking at the same Indian.

From Fort Wayne the expedition moved on to Fort Dearborn and then to Prairie du Chien. Wennebea, a Sauk whom they now met, Keating described as "a young and good looking Indian . . . of a lively, cheerful disposition . . . to us he was always uniformly polite and obliging" (*ibid.*, vol. 1 p. 190). Perhaps so. But Seymour's portrait sketch of him is no better either as a likeness of its subject or as a detailed delineation of an Indian warrior in costume than was that of

Metea, or that of Blackman who appeared on the same plate. For Blackman, let it suffice to say that he was a Chippewa whose countenance the artist sketched in the middle of August at Fort Garry in Canada. The journalist then wrote that "this man had a peculiar expression on his face, which induced Mr. Seymour to take a likeness of him" (*ibid.*, vol. 2, p. 76). Of the three heads Blackman may be the best, but this group is enough to convince us (unless J. Hill as engraver has betrayed the painter) that Seymour ought never to set up as a portrait artist. Certainly, too, as far as this publication is concerned, Seymour missed the opportunity that J. O. Lewis made much of in the next few years: the recording of Indian costume and paint.

At Prairie du Chien the party was split; Seymour was in the section that moved by boat up the Mississippi to Fort Snelling. On June 26 they passed "Garlic cape. . . . In shape it represents a cone cut by a vertical plane . . . its height is about 400 feet. The peculiarity of its appearance has made it a celebrated landmark on the Mississippi. Mr. Seymour, whose pencil was frequently engaged in sketching the beautiful features of the Mississippi, took a hasty view of this as the boat passed near it" (*ibid.*, vol. 1, p. 267). The sketch, however, was not reproduced.

On approaching Lake Pepin, Keating allowed the guide to tell the story of Winona. "While the circumstances of this tale were related to us, Mr. Seymour was engaged in sketching this interesting spot" (pl. 14). Keating used the picture as his fourth plate because "it gives a correct idea of the scenery of the upper part of the Mississippi, which has never, we think, been accurately represented" (*ibid.*, vol. 1, pp. 284-285). Another picture that Seymour did on this occasion Keating regretted he could not reduce satisfactorily to the proper size; it was "a fanciful delineation of the tragic event" just related:

Mr. Seymour painted one of this kind, in which the landscape was represented with the most faithful accuracy, but which he animated and enlivened by the introduction of a numerous party of Indians, in whom the characteristics of the Dacotas were strikingly delineated. The unfortunate Winona was represented at the time when she was singing her dirge, and the various groups of Indians below indicated the corresponding effect upon the minds of the spectators. [*Ibid.*, vol. 1, p. 285.]

The remaining illustration in the first volume of the Narrative is a portrait of "Wanotan and His Son," full length, with tepees and landscape in background (pl. 15). Although the faces are miserably done, it is a more satisfactory picture than the earlier plate with the three heads, for here considerable attention has been given to details of costume. Wanotan, the Charger, Keating informs us, was "the most distinguished chief of the Yanktoanan tribe" and "one of the

greatest men of the Dakota nation." He was then only 28 and his son about 8. The real interest of Seymour's poorly engraved picture is made clear by Keating's written description of this Sioux chief:

The next day Wanotan came to pay us a formal visit; he was dressed in the full habit of an Indian chief; we have never seen a more dignified looking person, or a more becoming dress. The most prominent part of his apparel was a splendid cloak or mantle of buffalo skins, dressed so as to be of a fine white colour; it was decorated with small tufts of owl's feathers, and others of various hues. . . . A splendid necklace, formed of about sixty claws of the grizzly bear, imparted a manly character to his whole appearance. His leggings, jacket, and moccasins were in the real Dakota fashion, being made of white skins, profusely decorated with human hair; his moccasins were variegated with the plumage of several birds. In his hair, he wore nine sticks neatly cut and smoothed, and painted with vermilion; these designated the number of gun-shot wounds which he had received, they were secured by a strip of red cloth; two plaited tresses of his hair were allowed to hang forward; his face was tastefully painted with vermilion; in his hand he wore a large fan of feathers of the turkey; this he frequently used.

. . . the most singular dress was that of Wanotan's son, who, for the first time in his life, wore the distinguished national garb, in which he is represented in the Frontispiece plate to this volume. The dresses were evidently made for his father, and too large for him, so that they gave to his figure a stiff and clumsy appearance, which strongly reminded us of the awkward gait of those children who, among civilized nations, are allowed, at too early an age, to assume the dress of riper years, by which they lose their infantine grace and ease. . . . This lad wore a very large head-dress, consisting of feathers made of the war-eagle. . . . His dress was made of many ermine skins, variously disposed upon a white leather cloak. [Ibid., vol. 1, pp. 436-438.]

Wanotan had been sketched while the explorers were staying at Lake Travers. Before leaving that neighborhood, Seymour took a view of the lake showing the Columbia Fur Co.'s "fort, the Indian lodges near it, and also a scaffold, upon which the remains of a Sioux had been deposited. The horizon is bounded by a distant view of the Coteau des Prairies" (ibid., vol 2, p. 5). This picture Keating used as frontispiece for his second volume. At this point the expedition had passed from the headwaters of the St. Peter's (Minnesota) River to those of the Red River of the North.

The next scene we have from the pencil of the artist, made 2 days later (July 28), reports possibly the most curious buffalo hunt in the history of the frontier. Keating wrote that a bull buffalo "seemed to challenge a combat with our party; he traveled for about 2 miles abreast of us, and almost within gunshot; his eyes were intently bent upon us." Driven off by the dog, he would immediately return to watch the travelers. "This fearless character, so unlike that of buffaloes in general, excited our surprize and admiration; and accordingly we determined to spare him, and see how long he would continue to

travel with us." The temptation, however, was too strong for the Indians:

Seeing him stop at the same place where we had halted, a few of them, especially the youngest of the party, ran up to him, and in a few moments several balls, and perhaps a dozen of arrows, had reduced the animal to the last gasp. They then approached on all sides, and while he was engaged in keeping off those on his left, the youths on his right would come so near to him as to draw his attention to them; the animal appeared galled, his rage was extreme, but his weakness was equally so. At length some of them came very near to him, and caught hold of his tail; at that moment he was observed to be tottering; they all drew off, the animal fell, and after two or three convulsive throes he expired; a shout from the Indians announced the death of their victim. This seemed to be a schooling for the youngest of their party, a few of whom were mere boys. Mr. Seymour took a sketch of this singular diversion, which is represented in Plate 7; it is taken at the moment when the animal is tottering, but it does not express all the fire and rage he manifested to the last. [Ibid., vol. 2, pp. 21-22.]

On August 5 Long established Camp Monroe at Pembina on the international line where they stayed 4 days. There Seymour sketched a *bois brulé*, Keating recorded, but perhaps we have lost nothing in the omission of this "portrait" from the Narrative (ibid., vol. 2, p. 45). It is more interesting to have the picture of the "Indian Lodges at Camp Monroe," which was published as plate 8 and which shows both a skin lodge and a bark-covered one. "The plate gives a good idea of the dress, appearance, and attitudes of the Indians and half-breeds that surrounded us. It likewise exhibits two dogs, carrying burdens in the manner of pack-horses" (ibid., vol. 2, p. 48).

The explorers followed the Red River to Lake Winnipeg and then started their return journey up the Winnipeg River, headed for the north shore of Lake Superior. Early on this stage of the journey they were to pass three impressive waterfalls. The 20th of August found them encamped beside the Lower Falls of the Winnipeg. The picturesque quality of this river and its cataracts much impressed Keating:

The place of our encampment was characterized by one of those peculiar effects of water, which, once seen, leave an indelible impression upon the mind. After having passed over numerous rocks, which form diversified cascades (the whole height of which is about thirty feet), the water is suddenly received into a basin enclosed by high rocks, where it is forced to sojourn awhile, by the small size of the aperture through which it issues; here the waters present the characters of a troubled ocean, whose waves rise high and beat against the adjoining shores, and against the few rocky islands which are seen in the midst of this basin; it is to this character that the spot owes the name which it receives from the natives, "the fall of the moving waters." . . . We reached them in time to watch the beautiful effect of the setting sun, whose beams reflected by the stream imparted to it the appearance of a sea on fire. This was soon replaced by the moon, which cast a more placid light upon the waves, and heightened

the charm of the scenery by the melancholy mantle it spread over it . . . a spare growth of aspen, birch, spruce, and other evergreens . . . adds to the wild and barren appearance of the rocks . . . our tents were pitched so that we had a view of the splendid effect arising from the play of the moonbeams upon the surface of this oceanlike basin, and our eyes were constantly bent upon it until the noise of the cataract lulled us to sleep. [Ibid., vol. 2, pp. 91-92.]

Probably Keating was right: "The artist could not behold, without rapture, a scene so worthy of being painted." Seymour spent the remaining daylight sketching the falls from a rock projecting far into the water. The author, however, eventually had to drop his plan of reproducing this picture because "it was found impossible to retain their effect when reduced to the required size" (ibid., vol. 2, pp. 92-93).

On the 23d they passed the Slave Falls and the Upper Falls of the Winnipeg, both of which Seymour drew and Keating published as plates 9 and 10. At the upper part of the Slave Falls "there is a fine cascade, below which the rapids continue for a short distance, presenting a beautiful landscape" (ibid., vol. 2, p. 99). To his view Seymour gave added interest by showing the men in the act of portaging. A few miles farther upstream they came on the Upper Falls—for beauty, said Keating, "second only to the lower falls." Seymour's view of this double cascade, however, "was not taken at a favourable spot, as the rocky nature of the bank prevented him from landing at a place from which an advantageous view of both the falls could be obtained" (ibid., vol. 2, p. 100).

The explorers on the 25th entered the Lake of the Woods and stopped for breakfast at Cosse's Island. There Seymour sketched a view of the lake that was published as plate 11 (ibid., vol. 2, p. 109). No other drawing is mentioned until the Kakabikka Falls near Fort William were passed on September 11. Difficult access kept the artist from sketching more than a small portion of these falls (pl. 16), but his drawing was used for plate 12 (ibid., vol. 2, p. 139). The final contribution by Seymour to the dressing up of Keating's Narrative (pl. 13) is a view of the north shore of Lake Superior done on September 22—"a very correct delineation" of an area "somewhat west of the 'Otter's Head'" (ibid., vol. 2, p. 185).

By October 26, Seymour was once again in Philadelphia, after an absence of 6 months, and could settle down with his portfolio of sketches to prepare illustrations for the new report. Information is meager. Letters from Long to Macomb in the War Office Records of the National Archives show that the artist was paid \$1.50 a day for his services on the expedition and received \$280.50 for the 187 days between April 27 and October 30, 1823. In addition he was allowed \$127.99 for travel expense. A third notation is a statement

sent to Macomb in which Long declared Seymour's services were necessary for the preparation of the report of this 1823 exploring party and asking for him \$2 a day for 3 months. The final result in pictures has already been shown.

One further reference to Seymour's work on these expeditions shows that he was not content merely to do pencil sketches and water colors. Maximilian of Neu-Wied on July 23, 1832, visited the Peale Museum in Philadelphia. There he met Titian Ramsay Peale, who showed the specimens which he himself had collected on the western expedition. What particularly interested Prince Max in the museum were "some oil paintings of Indian villages and scenery by Seymour" (Maximilian in Thwaites, 1905, vol. 22, pp. 69-70). Unfortunately, this museum was dispersed many years ago.

Where are they now, these oils and the hundreds of unpublished landscape sketches that once filled the portfolio of this man who was the first to serve as staff artist on the United States Government exploring expeditions, who was the first to picture the western plains, the outlying ranges of the Rockies, the upper reaches of the Mississippi, and the wilds of Minnesota?

ACKNOWLEDGMENTS

For information about the Long-Roberdeau letters I am indebted to Richard G. Wood, of the War Records Office, National Archives. The letters of Long to Macomb (Buffalo, October 18, 1823; Philadelphia, November 6, 1823; Philadelphia, January 10, 1824) are to be found in the War Records Office, National Archives, Corps of Engineers, Letters Received, 1819-25, Nos. 1436, 1458, 1535.

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